FU ORIONIS

BRING YOUR OWN BINARY

BORCHERT, PRICE, PINTE & CUELLO (2022)

MNRAS 510, L37-41

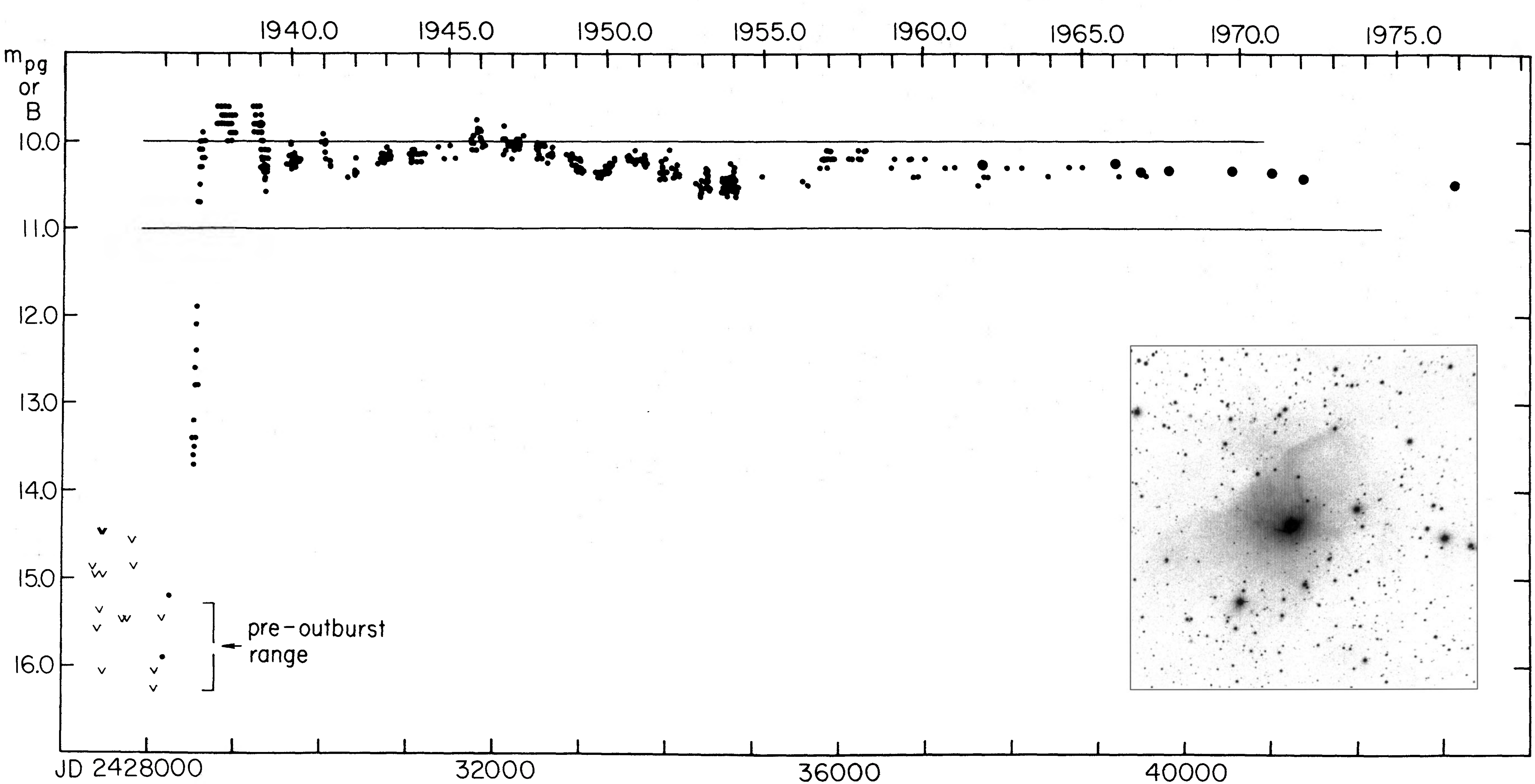
KITP BINARY22 WORKSHOP 4TH MAY 2022

MONASH University

Australian Government
Australian Research Council

DUST BUSTERS

WHAT HAPPENED IN 1936-1937?



ERUPTIVE PHENOMENA IN EARLY STELLAR EVOLUTION*†

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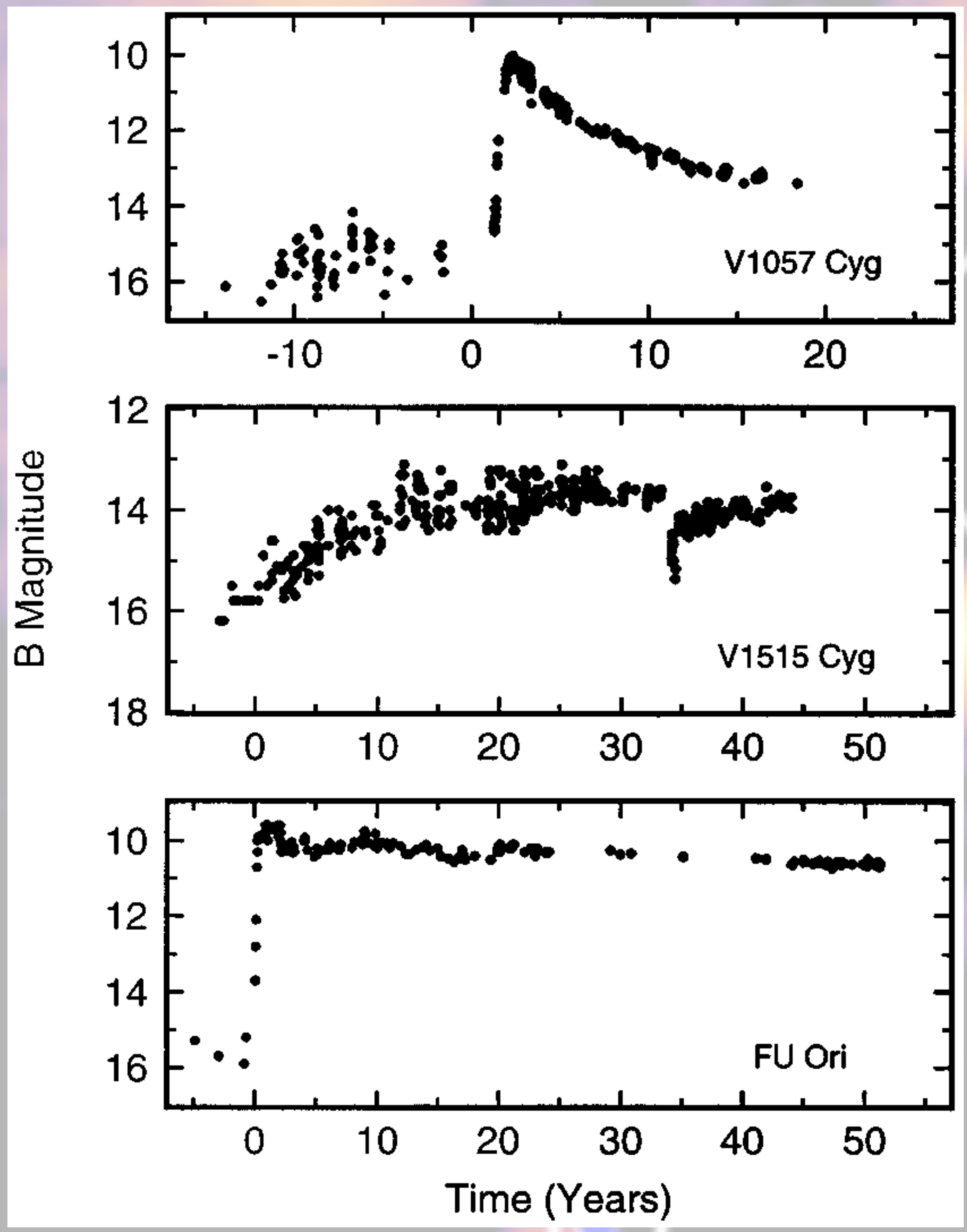
Received 1977 February 22; accepted 1977 April 25

THE FU ORIONIS PHENOMENON[1]

Lee Hartmann and Scott J. Kenyon

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 01238



- Rapid change in luminosity over short timescales that persists for decades
- Associated with reflection nebulae, winds and outflows

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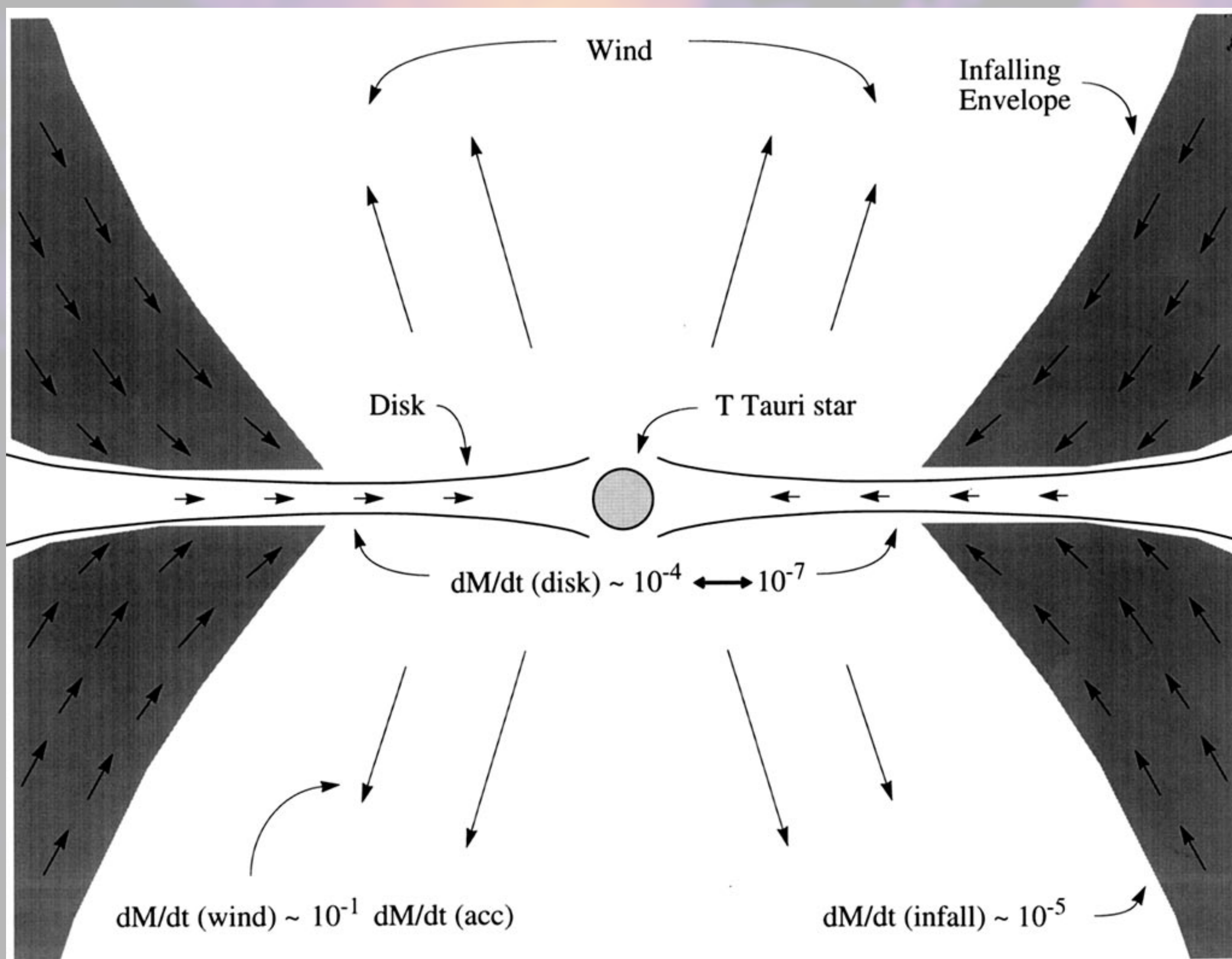
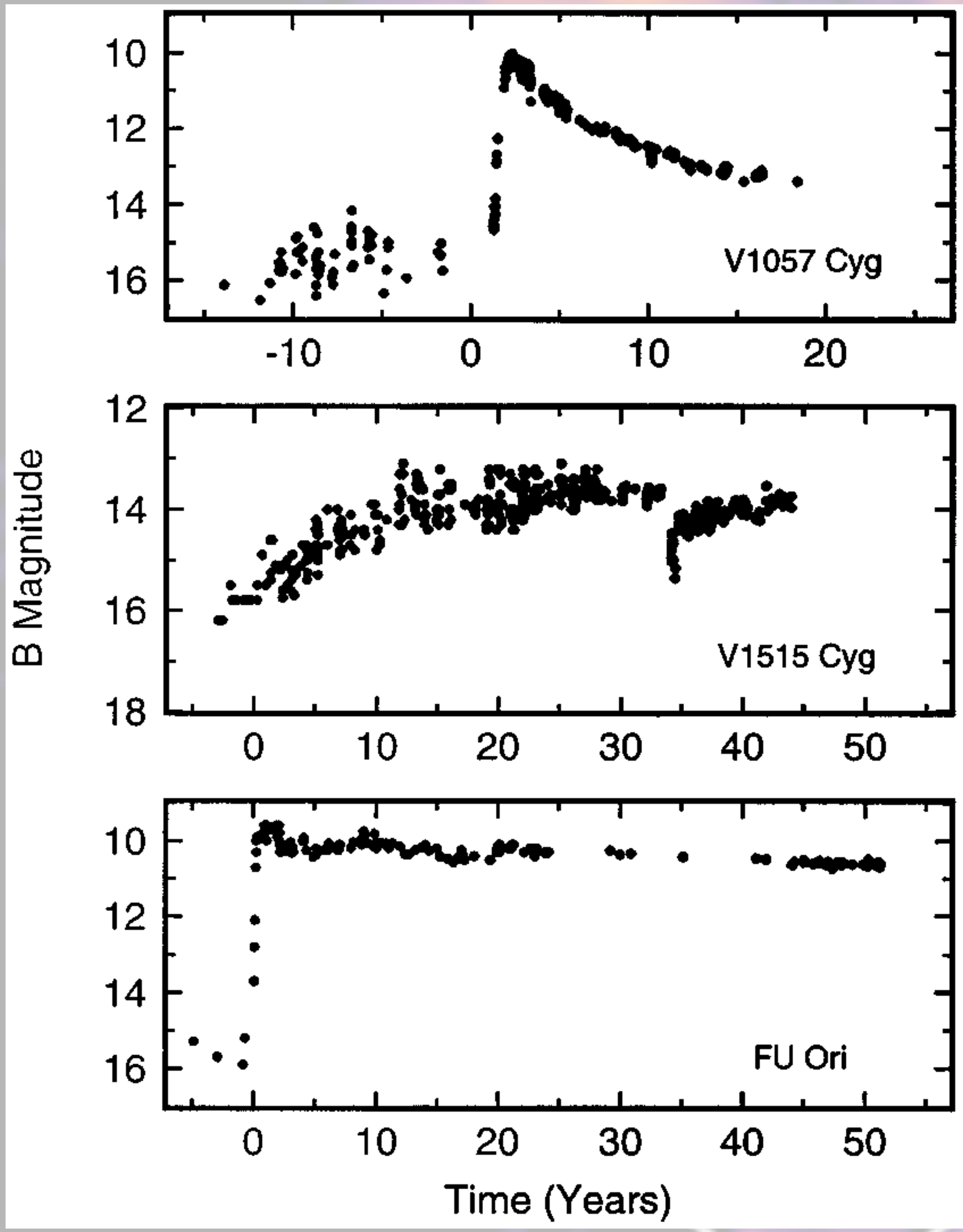


Figure 1 Schematic picture of FU Ori objects. FU Ori outbursts are caused by disk accretion increasing from $\sim 10^{-7}$ $M_\odot$ yr^{-1} to $\sim 10^{-4}$ $M_\odot$ yr^{-1}, adding $\sim 10^{-2}$ $M_\odot$ to the central T Tauri star during the event. Mass is fed into the disk by the remanant collapsing protostellar envelope with an infall rate $\lesssim 10^{-5}$ $M_\odot$ yr^{-1}; the disk ejects roughly 10% of the accreted material in a high-velocity wind.

- Associated with sudden increase in accretion rate through circumstellar disc
- $\dot{M} \sim 10^{-4}\,\mathrm{M_\odot/yr}$
- Winds/outflows
- Main mode of mass growth for young stars?

THE RISE TIME PROBLEM

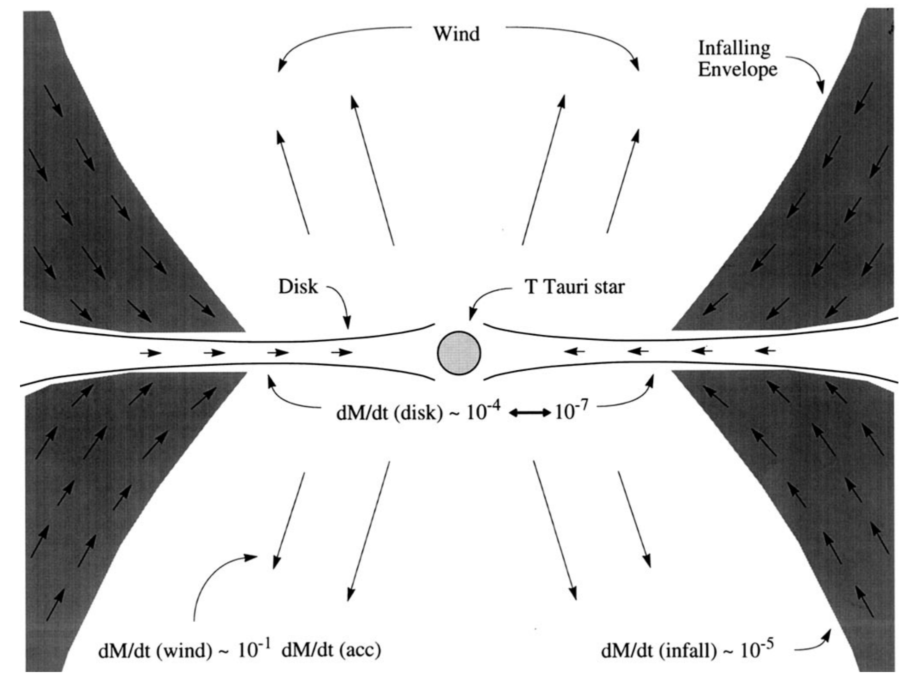


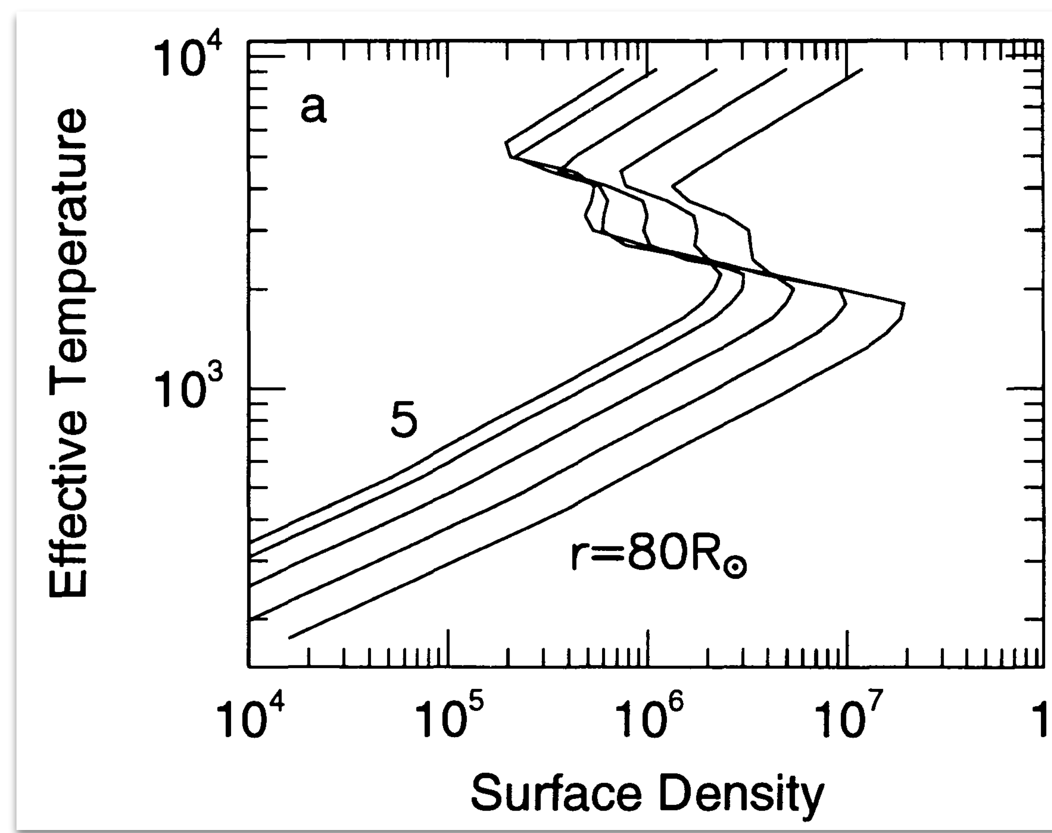
The rise of FU Ori systems on a time-scale less than even the dynamical time-scale at 1au implies that the sudden increase in dissipation at the onset of outburst must occur at radii < 1 au (Clarke, Lin & Pringle 1990)

To explain the fastest rise times of a year, the eruption must involve disc regions smaller than one au [because disc evolution will occur on timescales much longer than an orbital period (Hartmann & Kenyon 1996)

POSSIBLE EXPLANATIONS

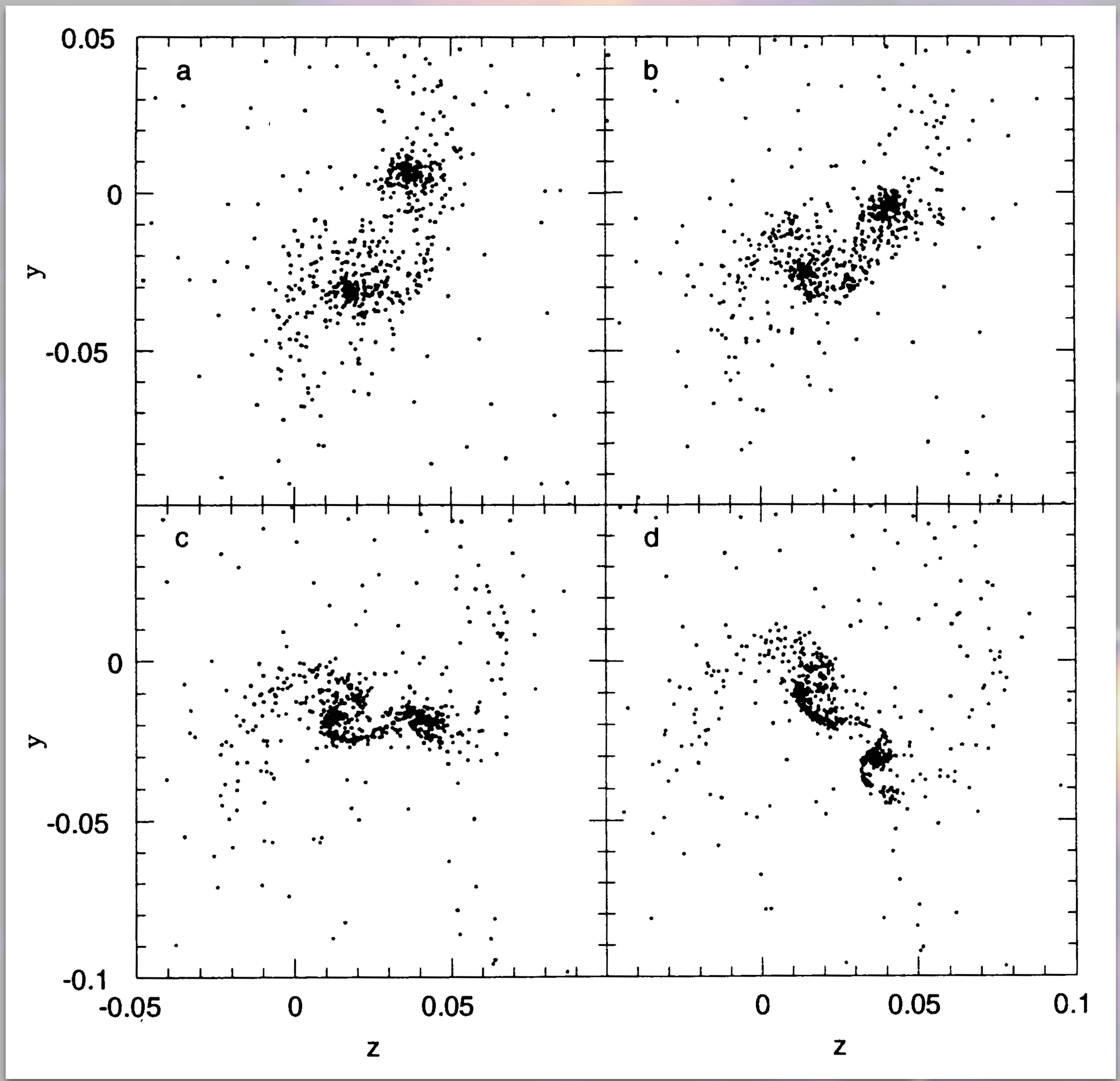
- Disc thermal instability (Clarke et al. 1990; Bell & Lin 1994; Bell+1995; Kley & Lin 1999)
- Binary-disc interaction? (Bonnell & Bastien 1992). Possibly triggering thermal instability?
- Planet-disc interaction triggering thermal instability (Clarke & Syer 1996; Lodato & Clarke 2004)
- Tidal disruption of young, massive planets (Nayakshin & Lodato 2012)
- Pile-up of material due to dead zones/layered accretion (Martin, Lubow & Livio 2012; Martin & Livio 2014; Kadam+2020; Vorobyov+2020)
- Accretion outbursts in self-gravitating discs (Bae+2014)
- Sudden increase in turbulence due to transition between gravitational instability and magnetic instability (Martin & Lubow 2013; Martin & Livio 2014)





A BINARY MODEL?

Bonnell & Bastien (1992)



- Tidal effects from a companion induce enhanced accretion rates
- "Accretion rates can exceed $10^{-4}\,M_{\odot}/yr$"
- But need very close encounter (< 1 au) for fast rise?

FU ORI IS A BINARY!

Wang et al. (2004)

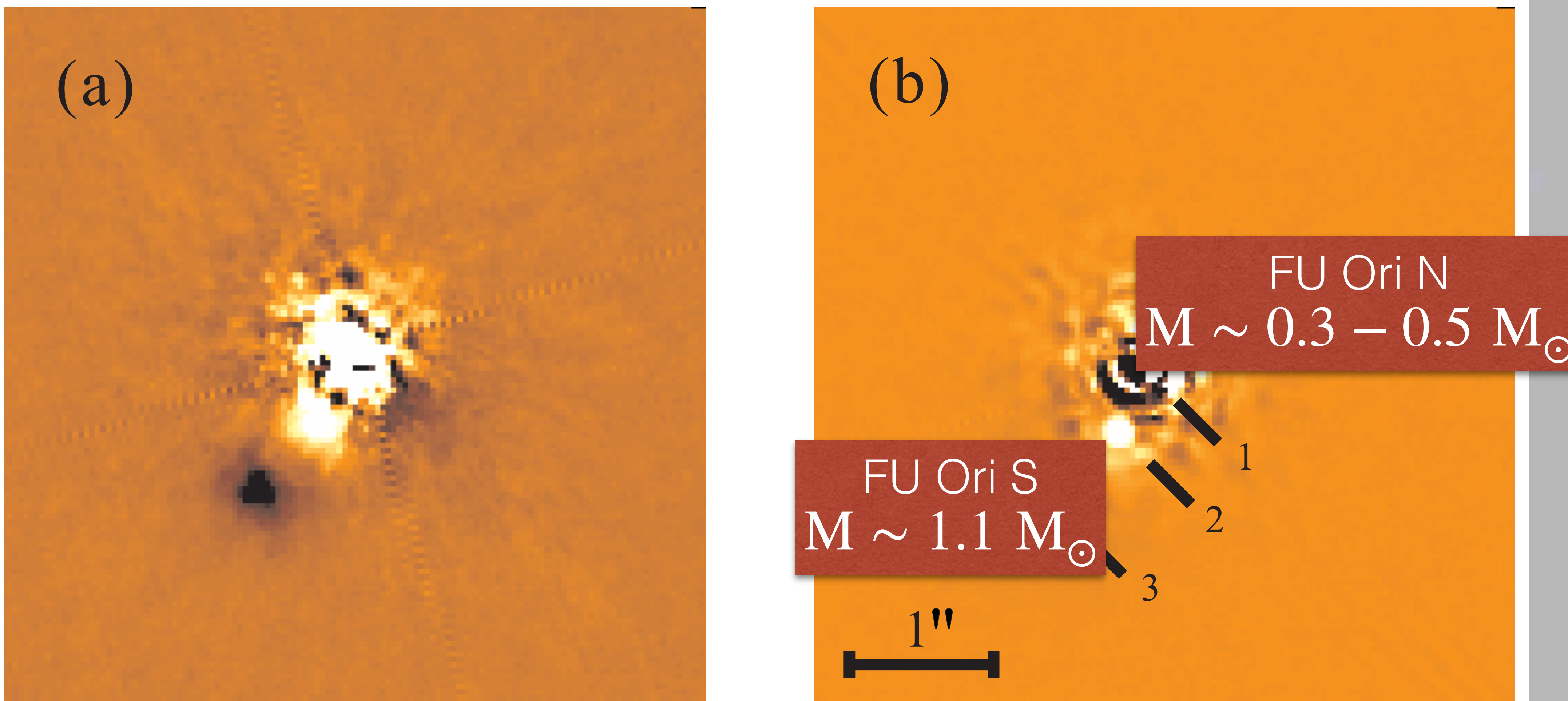


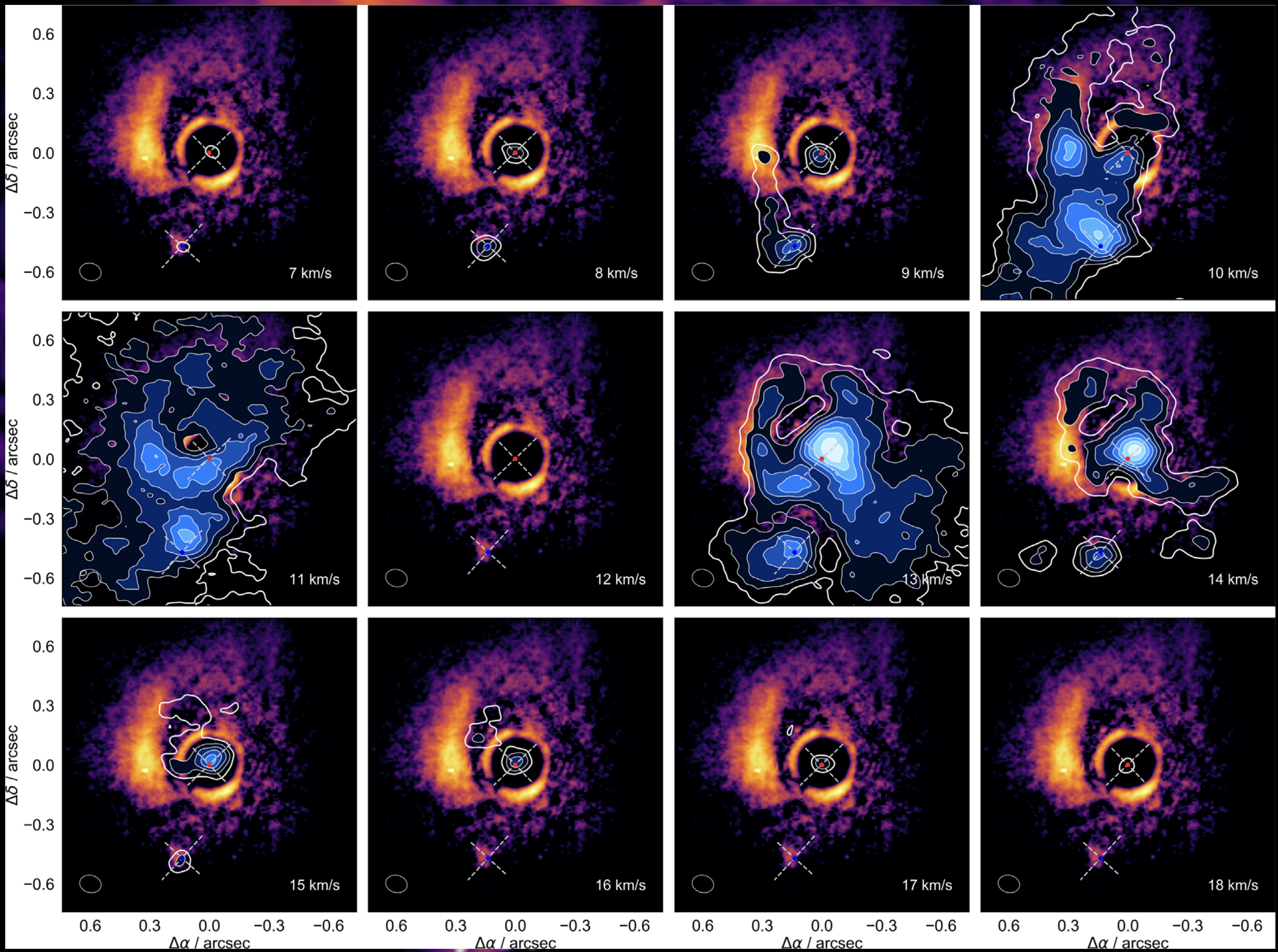
FIG. 1.—PSF-subtracted images of FU Ori, (*a*) in the *J* and (*b*) in the K_s band. North is up, and the east is to the left. The positions of FU Ori, FU Ori S, and the visual companion of the PSF reference star are indicated with numbers 1–3 in (*b*). The image scale is marked in (*b*).

"…the primary in the FU Ori binary system is in fact FU Ori S, rather than FU Ori itself"

…but period ~ 2700 yr if on circular orbit at 225 au.
Binarity seems irrelevant to the 1 yr onset of outburst.

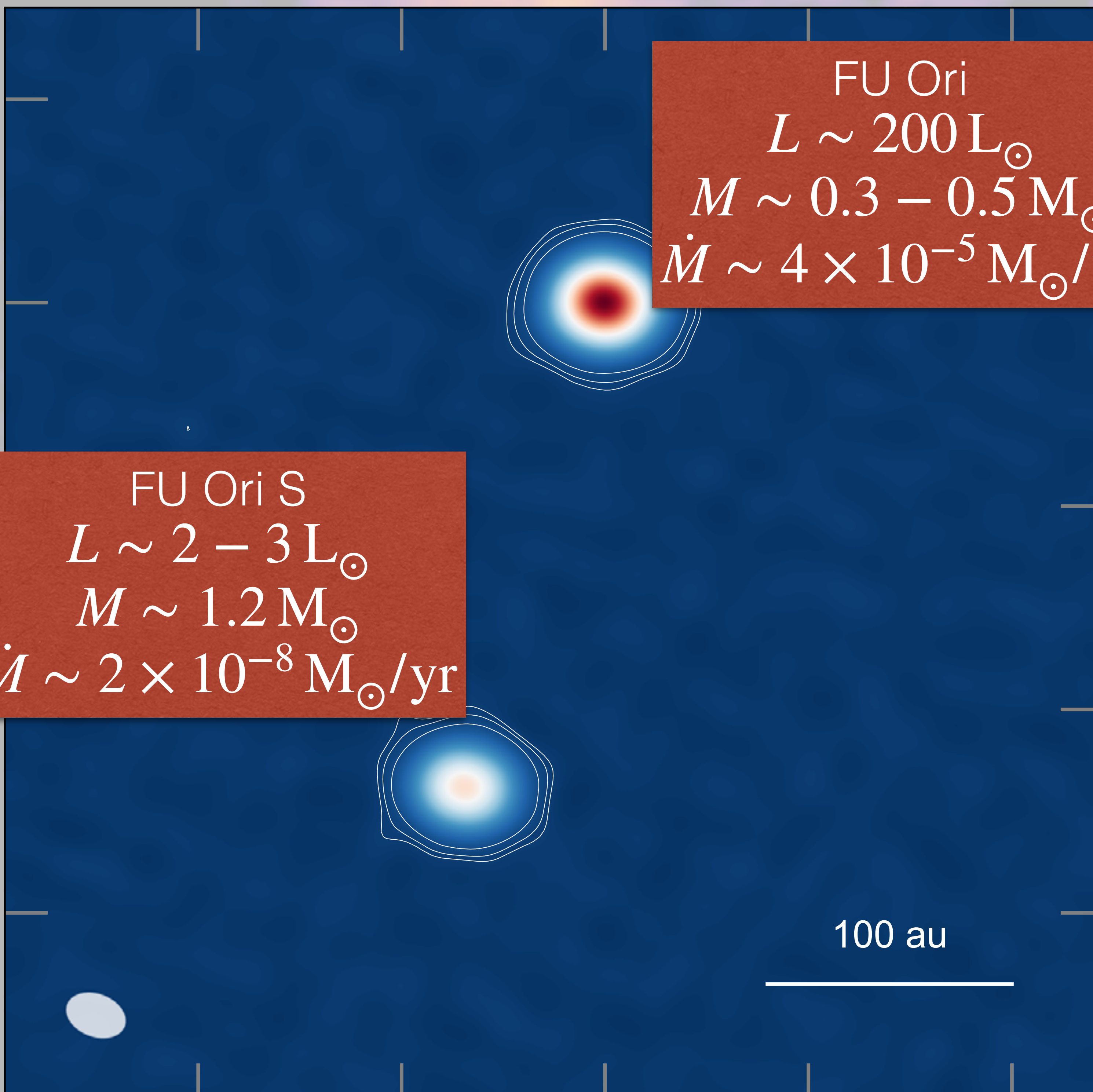
FU ORI IS AN INTERACTING BINARY!

Scattered light imaging: Liu et al. (2016); Takami et al. (2018); Perez et al. (2020)



FU ORI WEIRDNESS

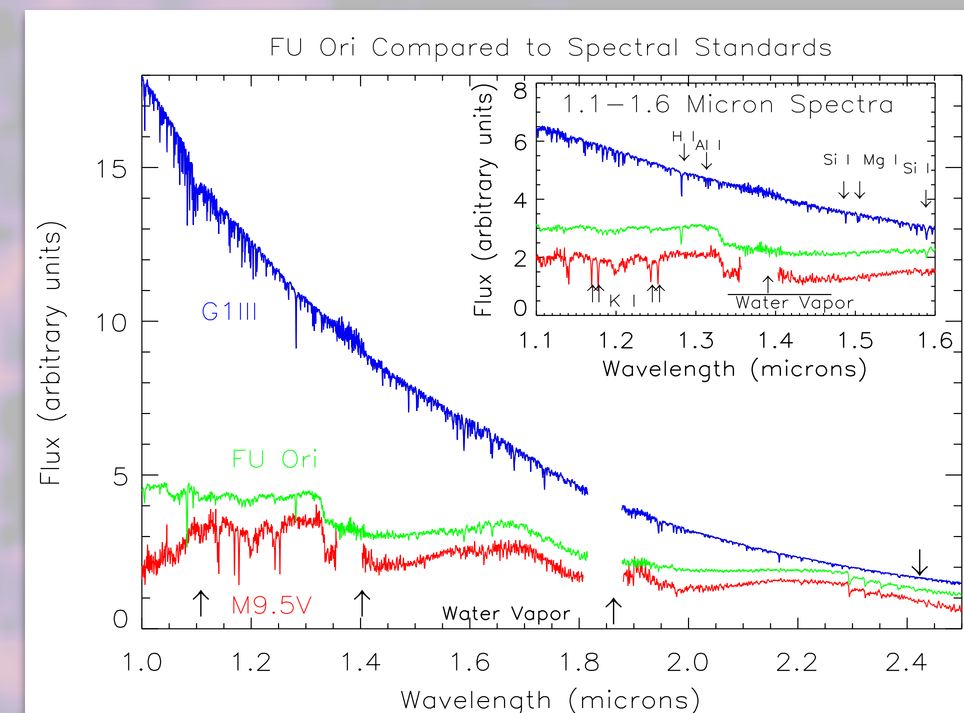
Beck & Aspin (2012); Perez et al. (2020)



FU Ori
$L \sim 200\,L_\odot$
$M \sim 0.3 - 0.5\,M_\odot$
$\dot{M} \sim 4 \times 10^{-5}\,M_\odot/yr$

FU Ori S
$L \sim 2 - 3\,L_\odot$
$M \sim 1.2\,M_\odot$
$\dot{M} \sim 2 \times 10^{-8}\,M_\odot/yr$

ALMA continuum image at 1mm (Perez+2020)



Poor spectral fits: FU Ori N fit by M-dwarf spectra in IR but a G-type giant in optical?? (Beck & Aspin 2012)

POSSIBLE EXPLANATIONS

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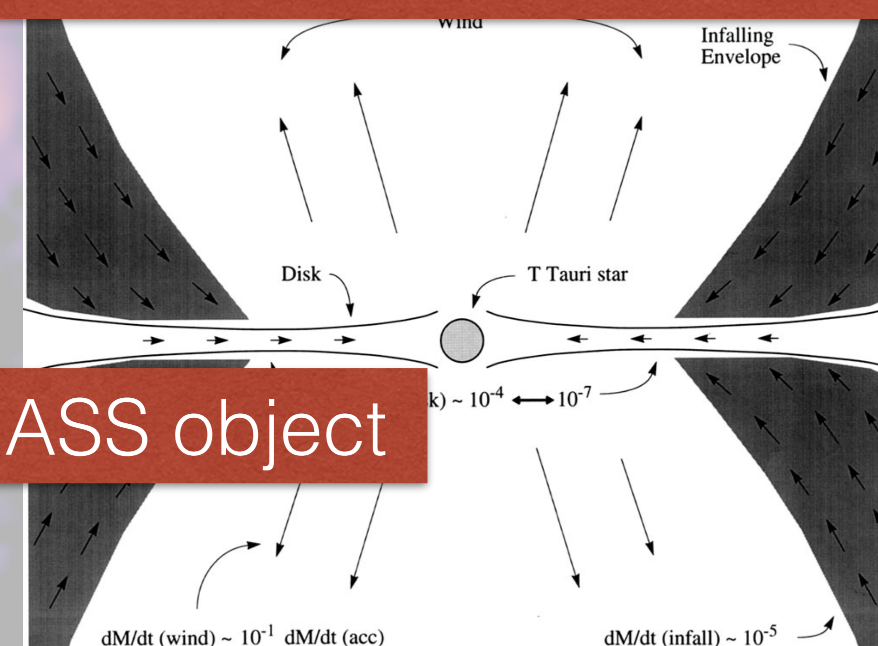
- Planet-disc interaction triggering thermal instability

YOU ARE LOOKING AT THE WRONG STAR!

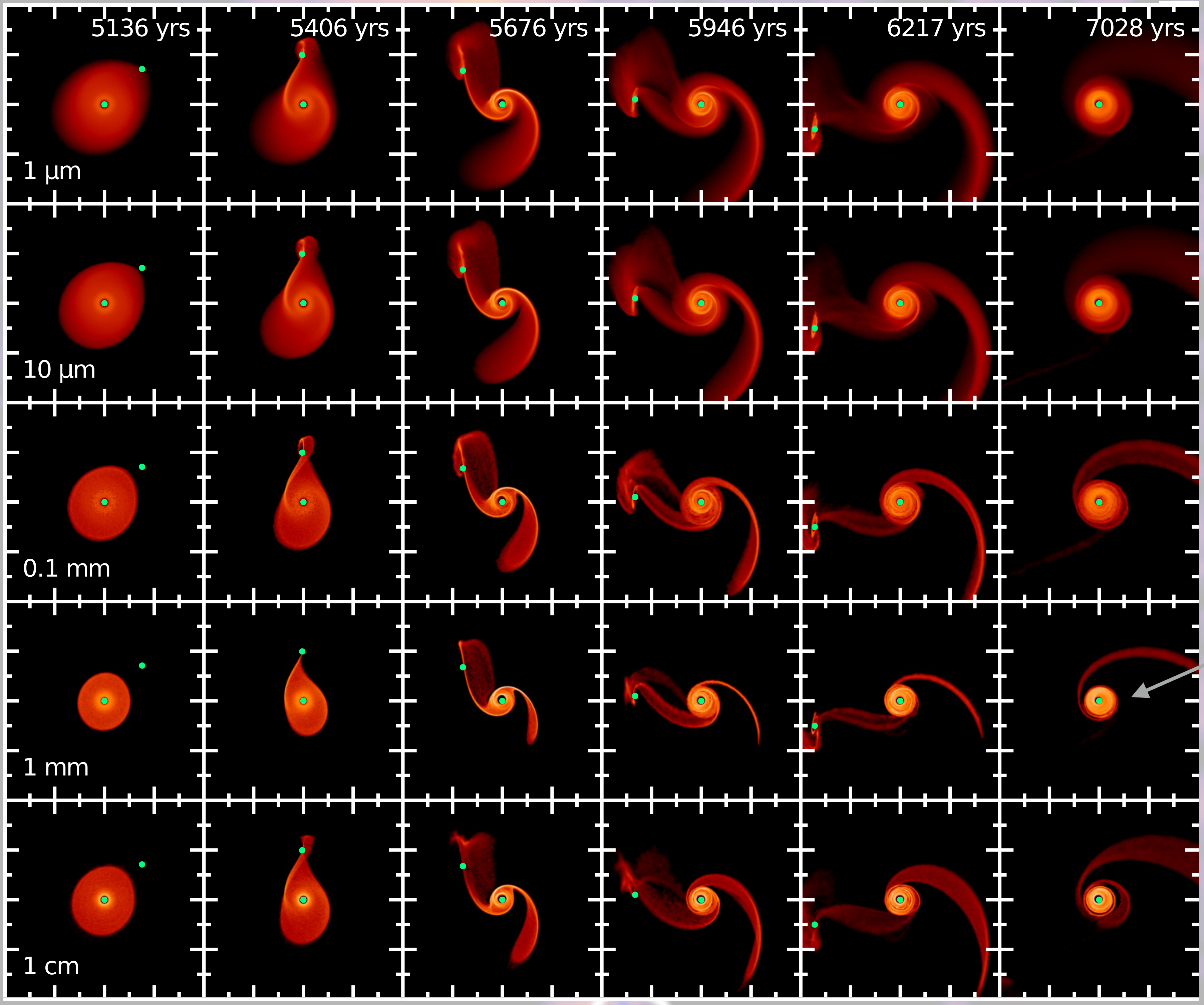
- Accretion outbursts in self-gravitating discs (Bae+2014)
- Sudden increase in turbulence due to transition between gravitational instability and magnetic instability (Martin & Lubow 2013; Martin & Livio 2014)



Outburst is on the LOW MASS object

F U O R I O N I S A S A F L Y B Y ?

Cuello et al. (2019, 2020)

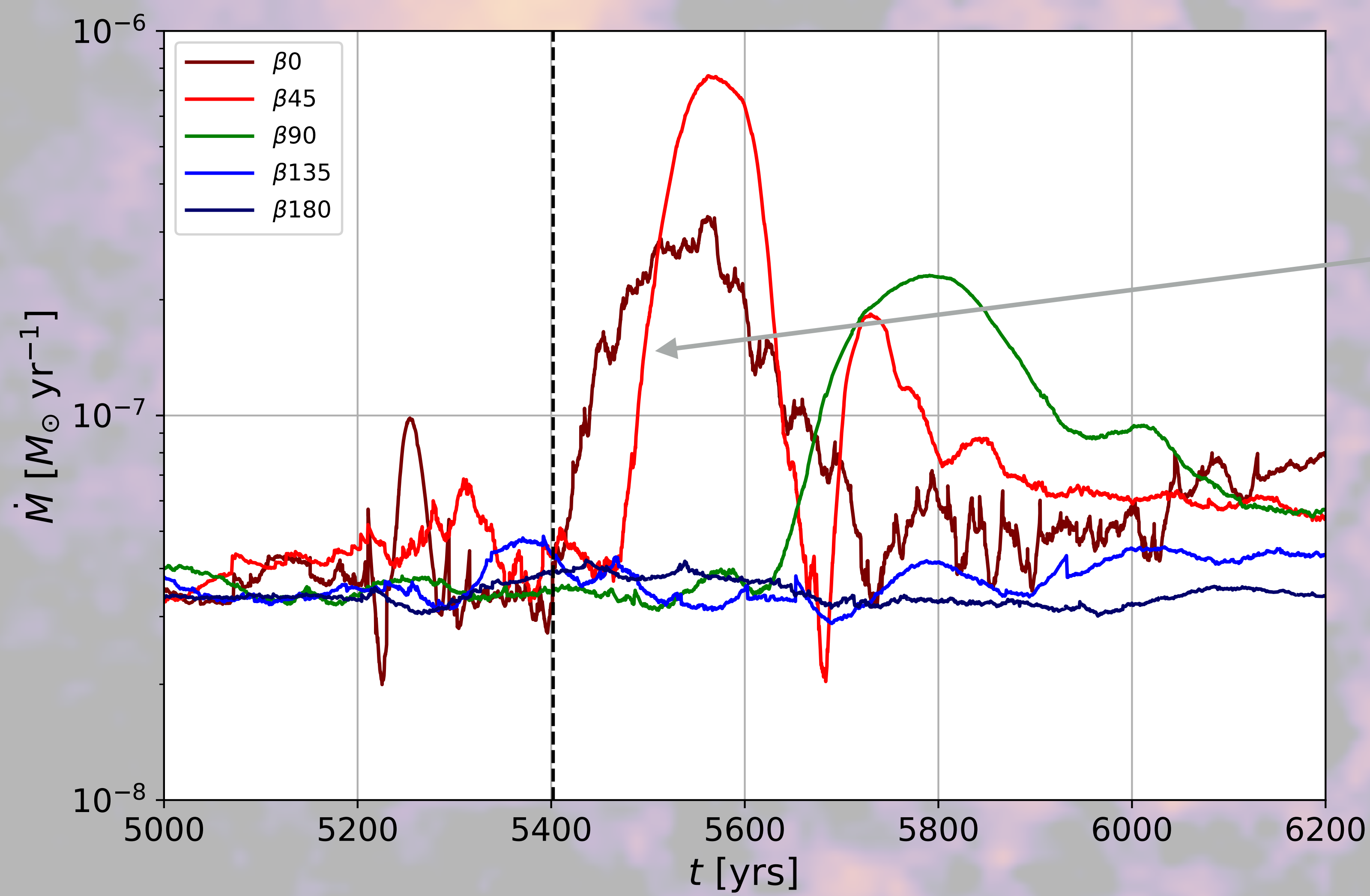


- Locally isothermal simulations with prescribed radial temperature profile
- Simulating dust-gas mixture with different grain sizes

Make compact dust disc in mm emission

FU ORIONIS AS A FLYBY?

Cuello et al. (2019, 2020)

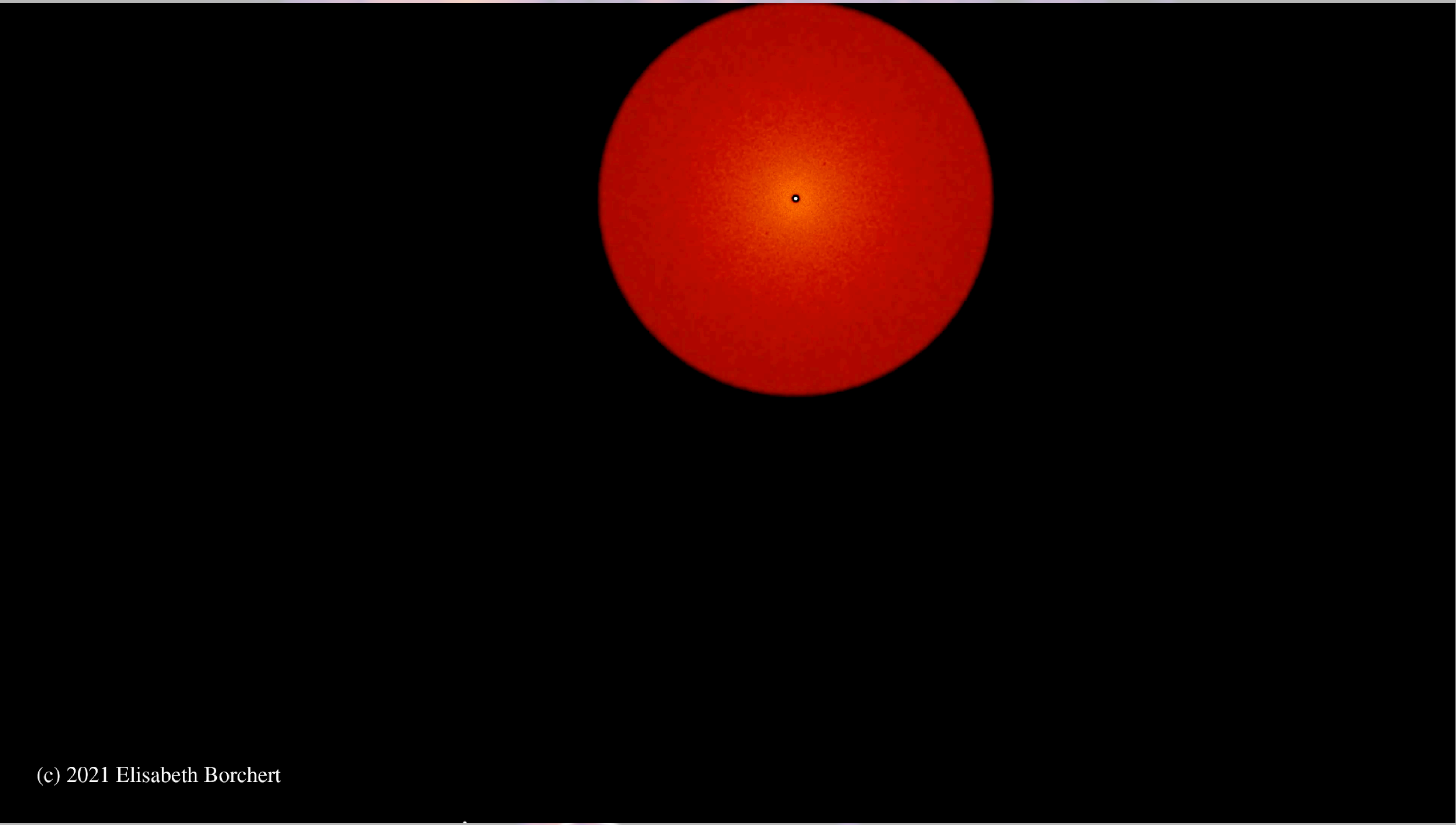


Rapid increase in $\dot{M}$ but rise time ~decades not 1-2 years

Also need to account for temperature evolution during the flyby

F U O R I O N I S A S A F L Y B Y

Borchert, Price, Pinte & Cuello (2022)



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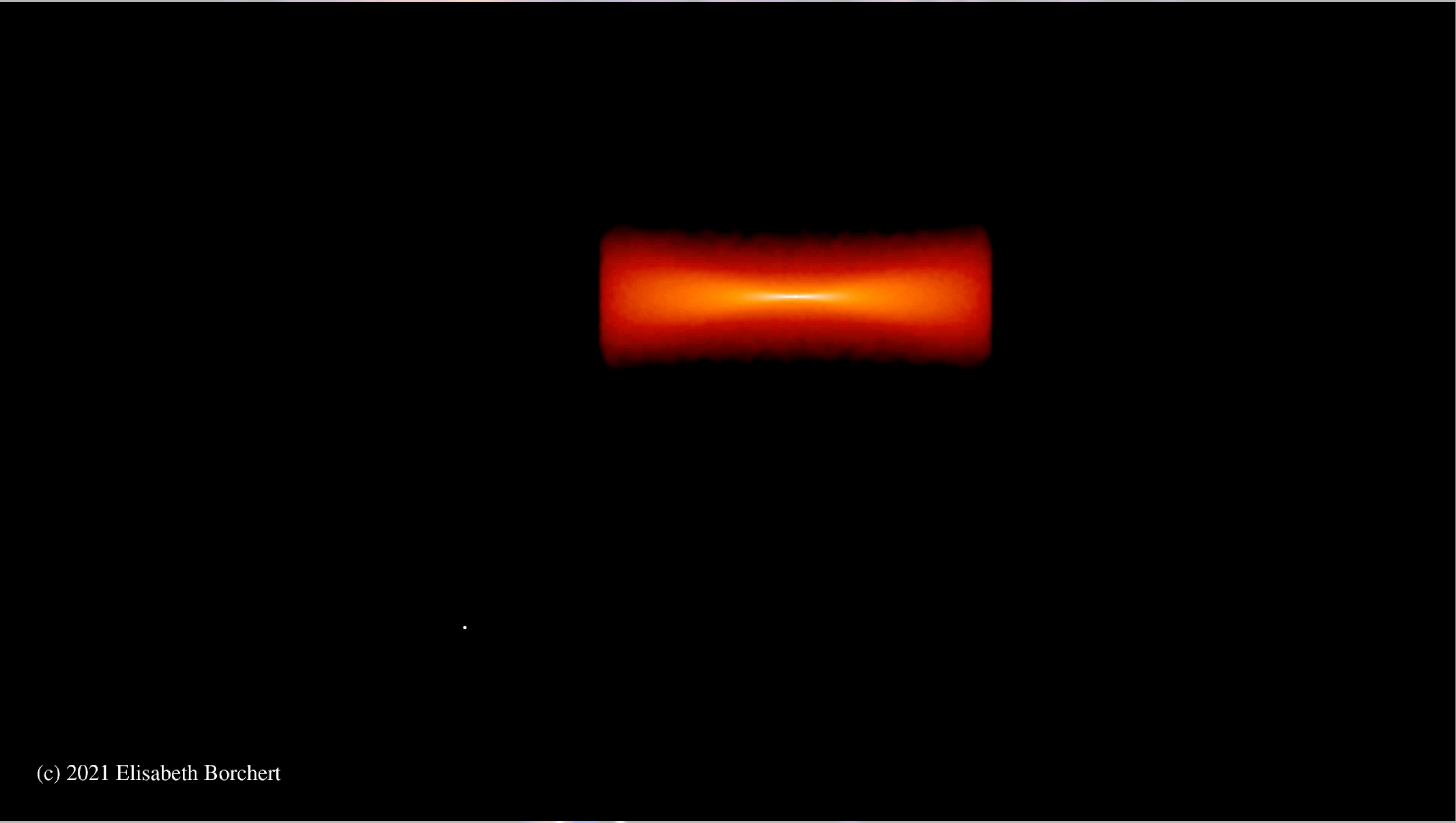
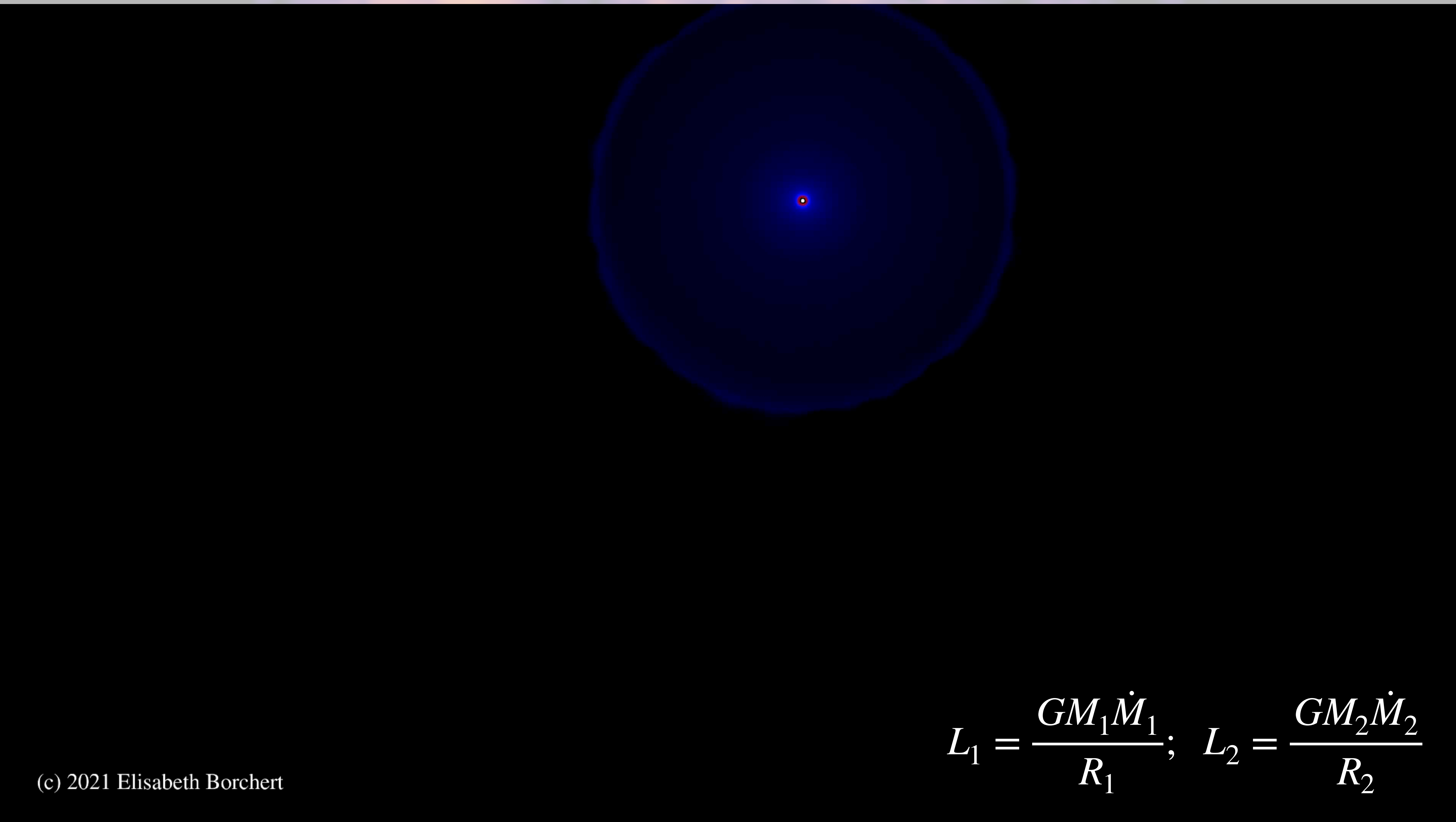


Similar idea by Vorobyov et al. (2021) but kyr timescales

TEMPERATURE EVOLUTION

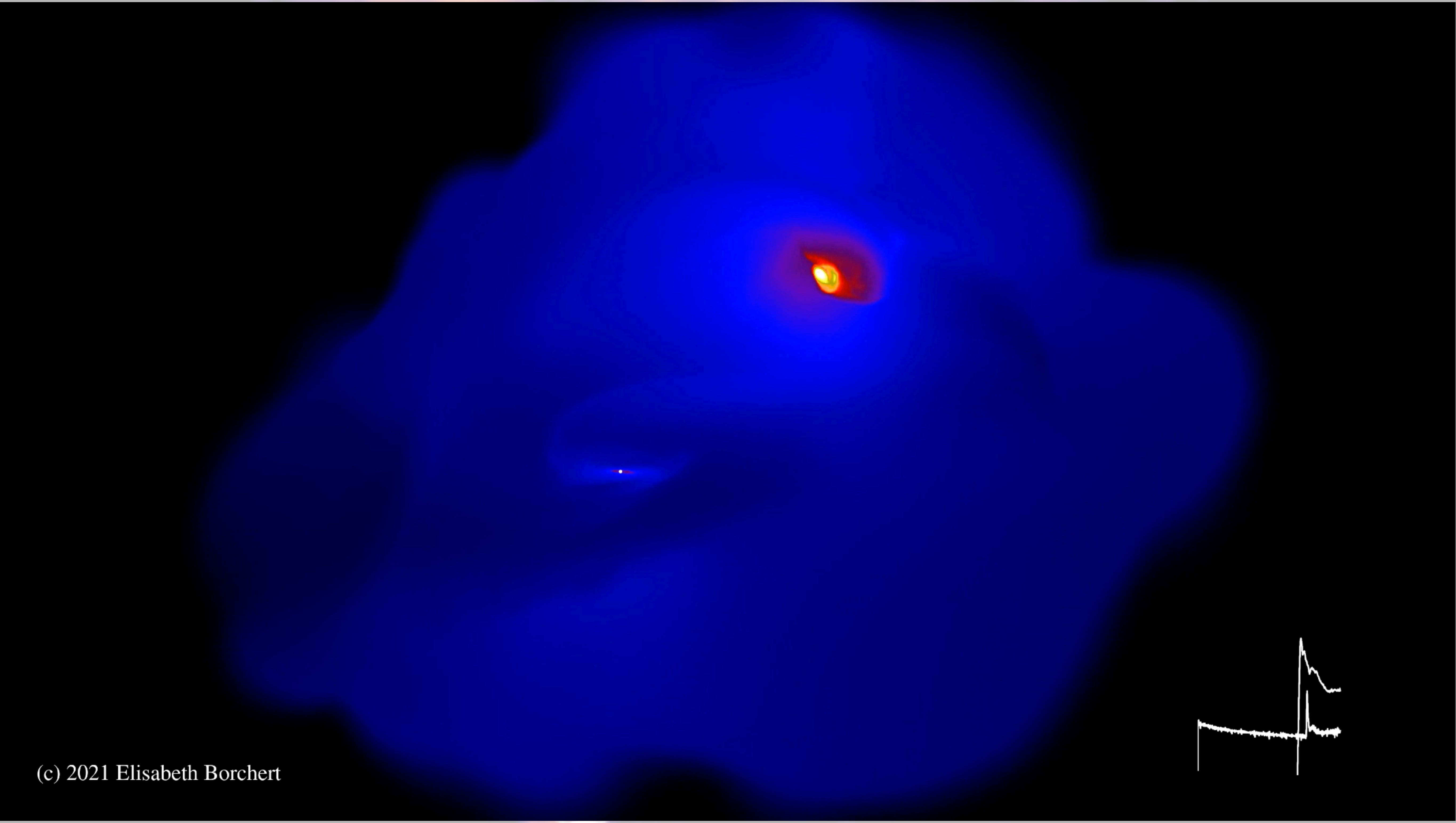
Live-coupling of MCFOST Monte Carlo radiation transport code for temperature evolution



$$L_1 = \frac{GM_1\dot{M}_1}{R_1}; \quad L_2 = \frac{GM_2\dot{M}_2}{R_2}$$

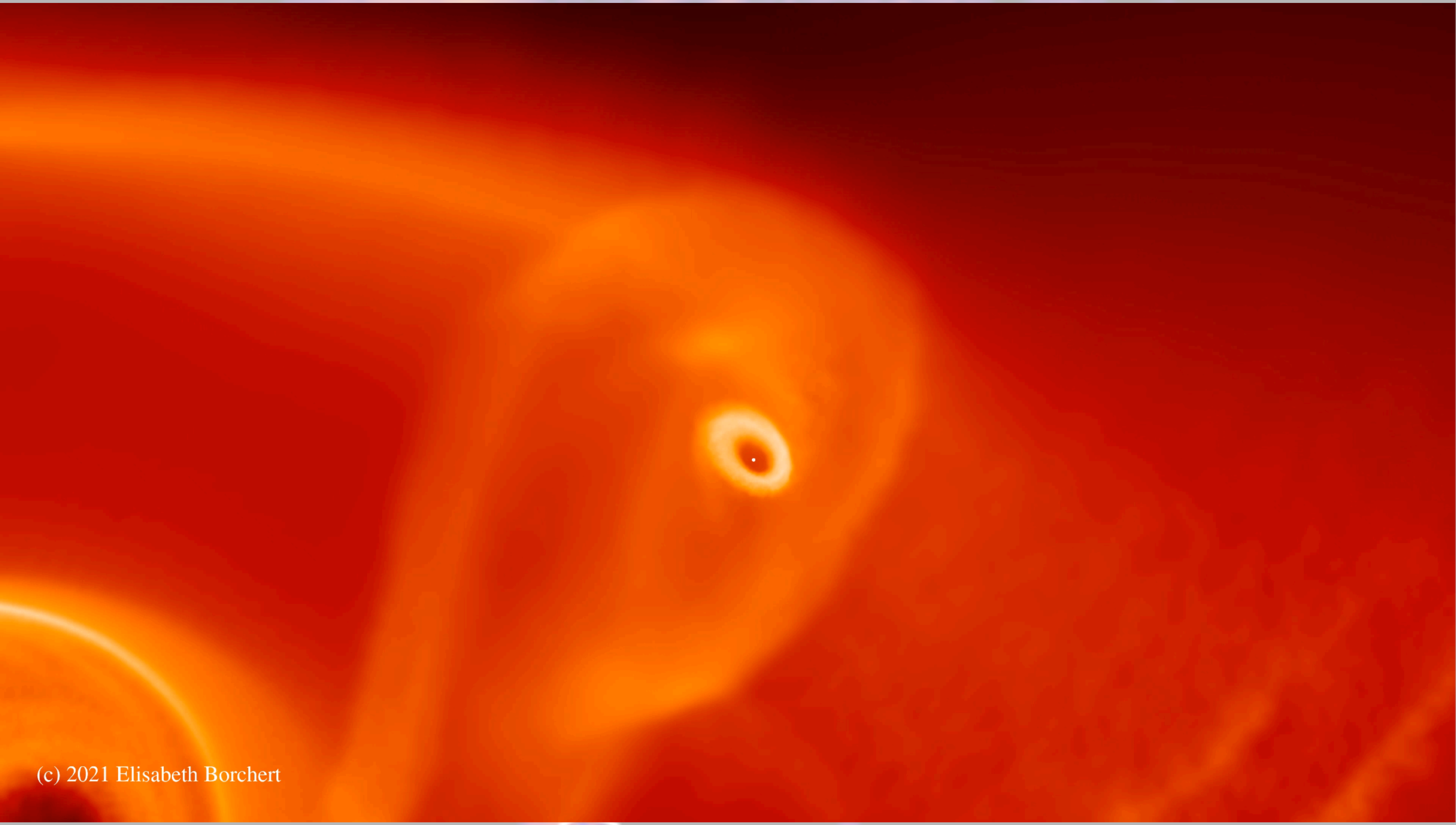
F U O R I O N I S A S A F L Y B Y

Borchert, Price, Pinte & Cuello (2022)



Audio thanks to: https://github.com/erinspace/sonify

HOW TO ACCRETE LIKE HELL

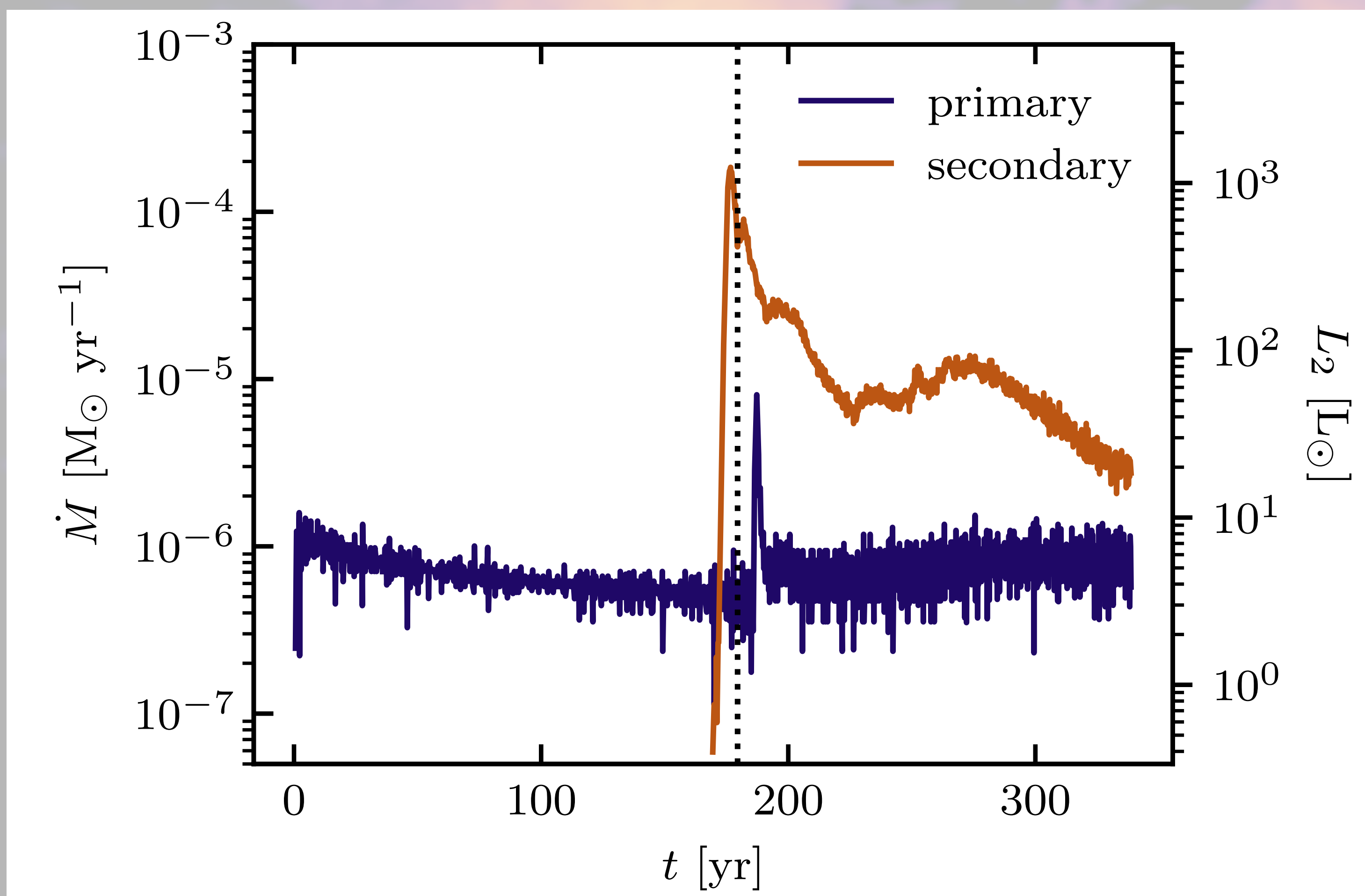


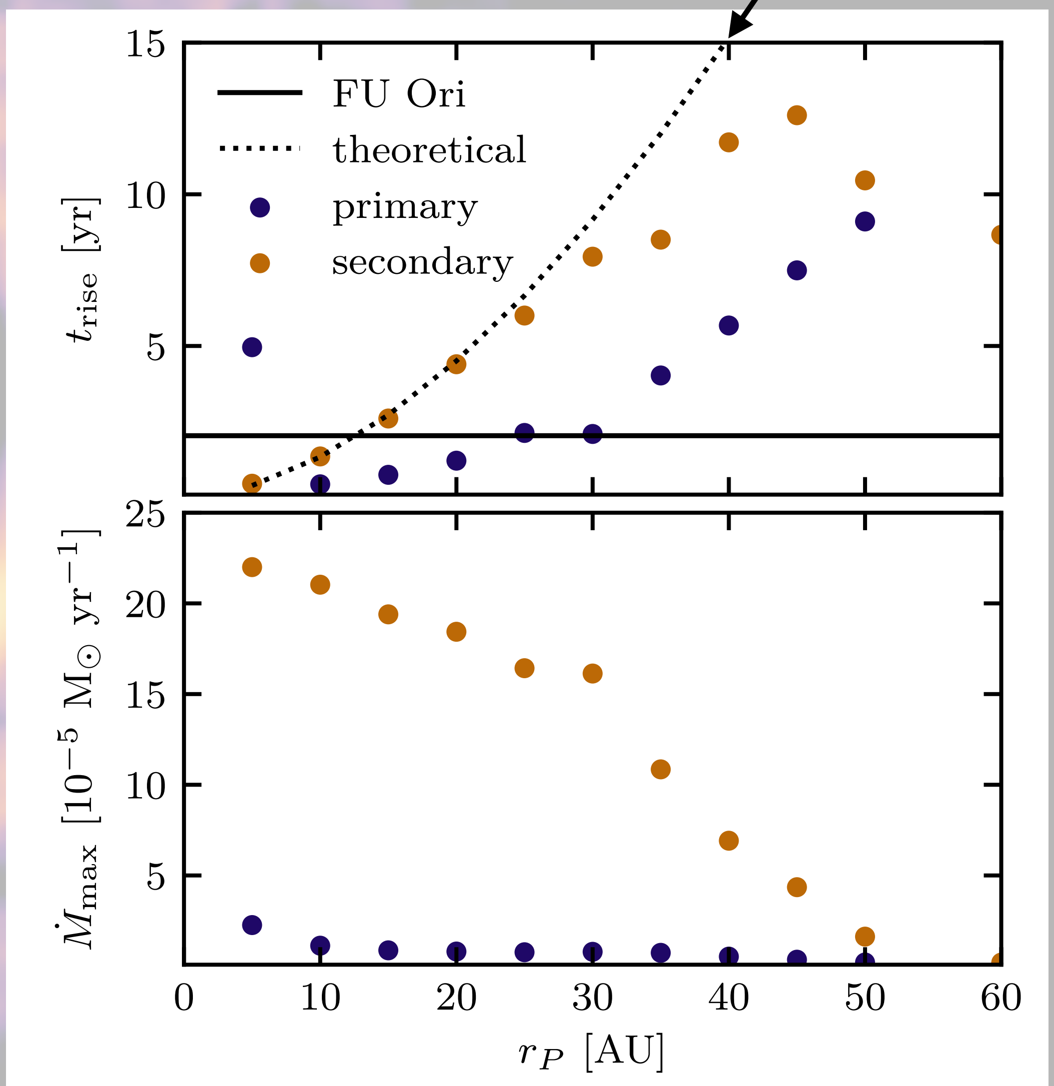
High $\dot{M}$ occurs when accretion flows are misaligned!

EXPLAINING THE FAST RISE OF FU ORIONIS

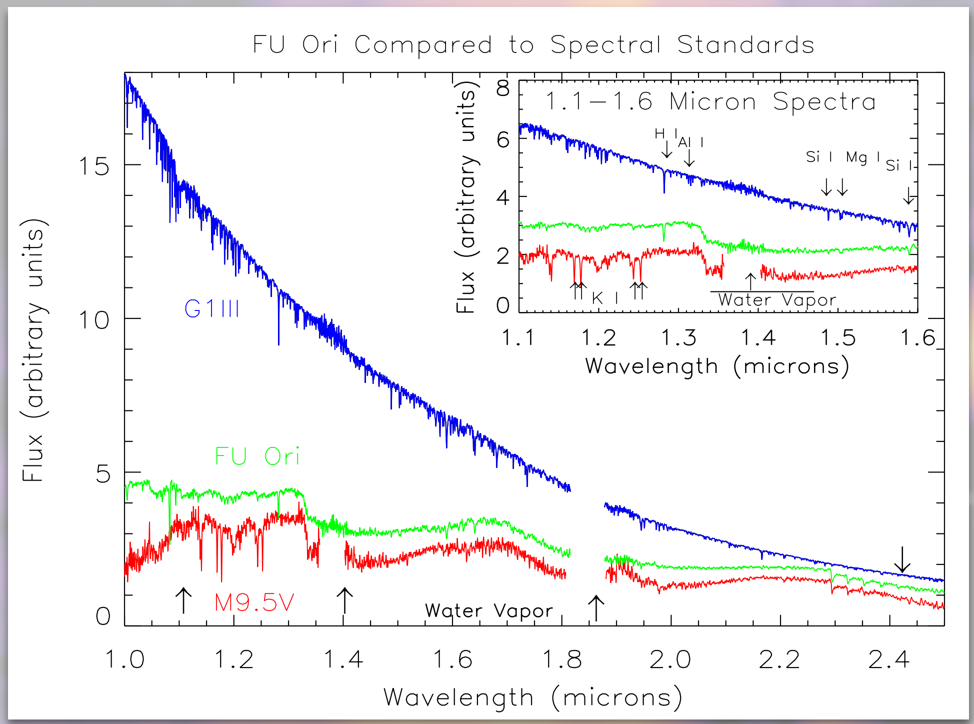
Borchert, Price, Pinte & Cuello (2022)

$$t_{\rm rise} = \frac{L}{v}$$





WHAT ELSE CAN YOU EXPLAIN?



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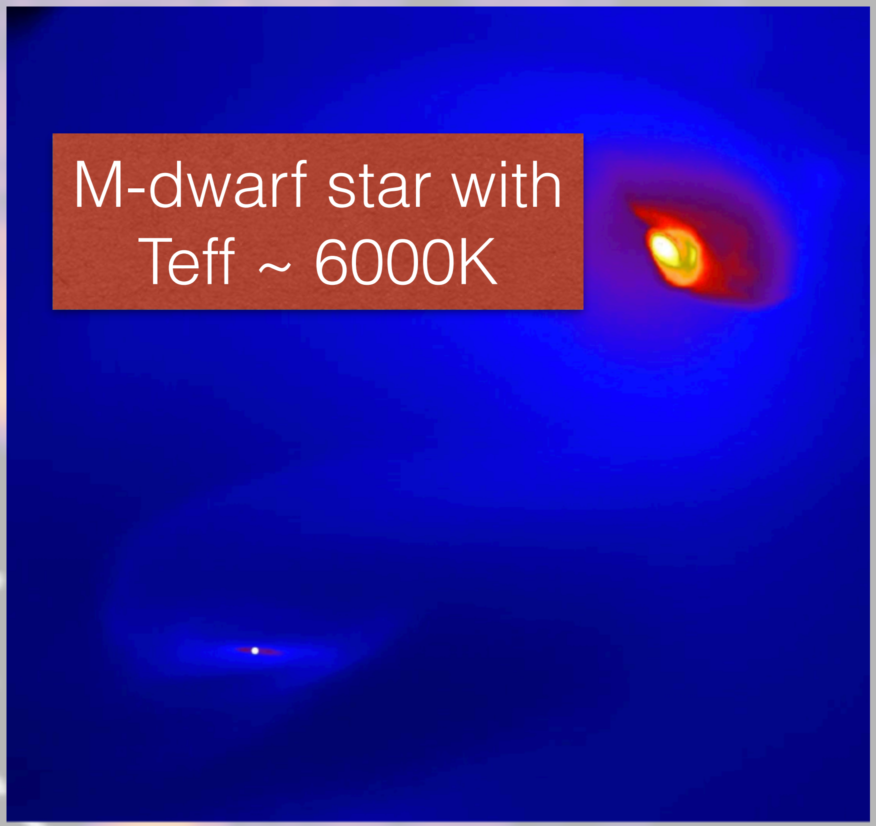
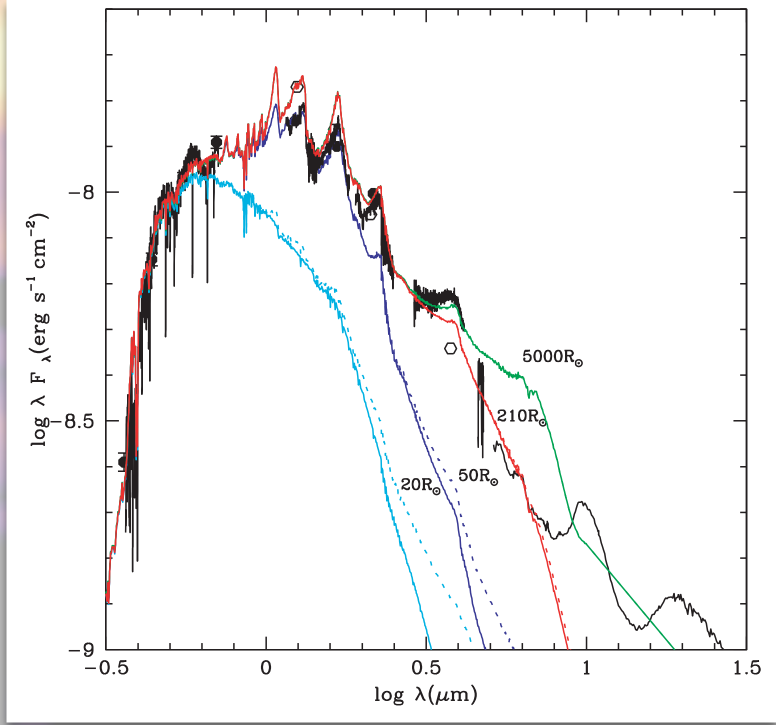


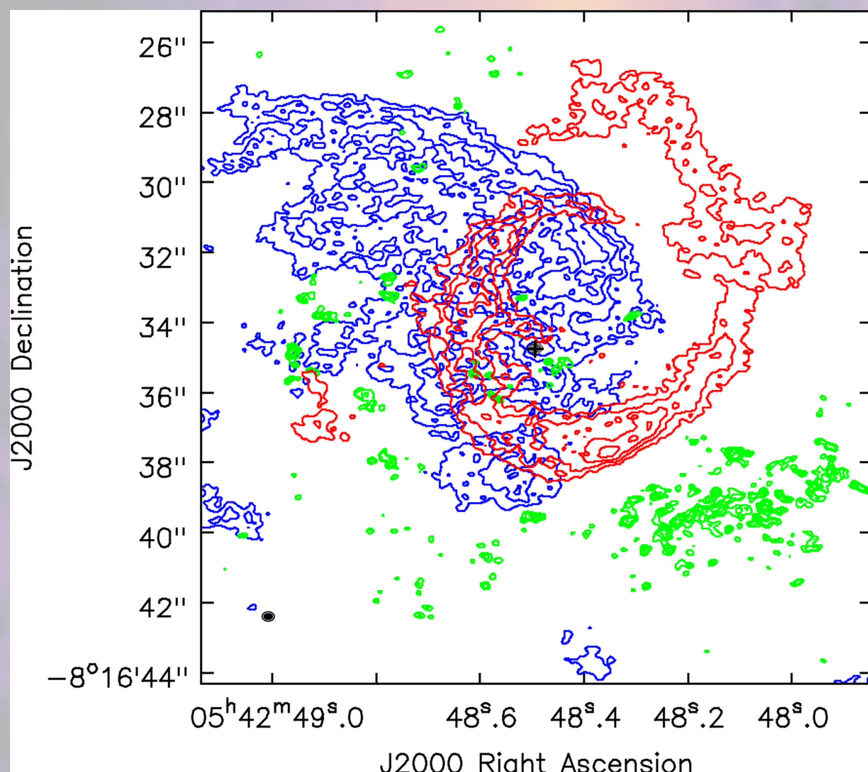
M-dwarf star with Teff ~ 6000K

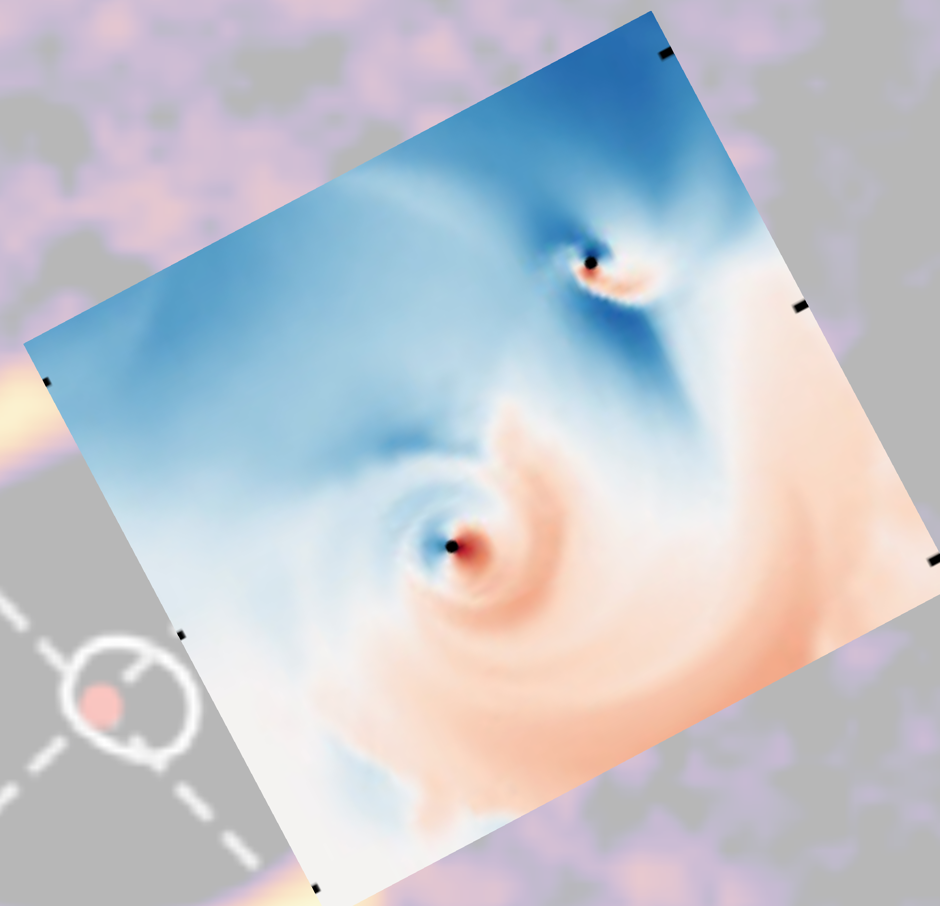


see also Zhu et al. (2007) fit to SED

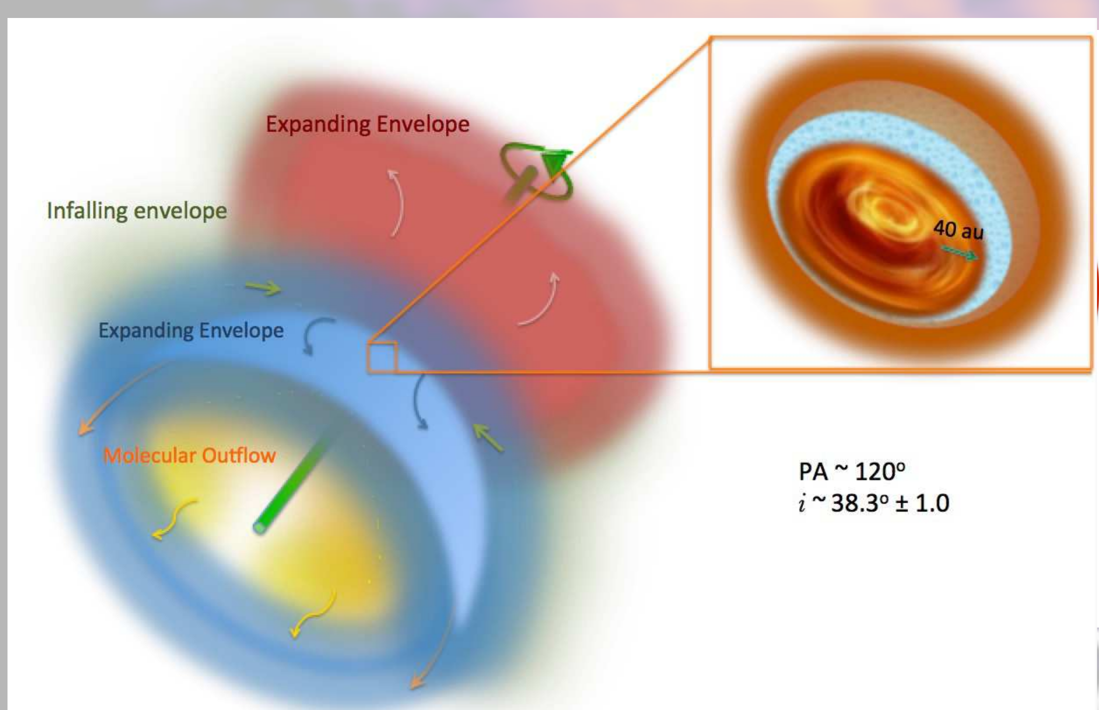
DOUBLE-CONE OUTFLOWS OR OUT-OF-PLANE MOTIONS?

The ALMA Early Science of V2775 Ori 7





Borchert et al. (2022, submitted)



The ALMA Early Science view of FUor/EXor objects. I. Through the looking-glass of V2775 Ori★

The ALMA Early Science View of FUor/EXor objects. II. The Very Wide Outflow Driven by HBC 494 ★

The ALMA Early Science View of FUor/EXor objects. III. The Slow and Wide Outflow of V883 Ori ★

The ALMA Early Science View of FUor/EXor objects. IV. Misaligned Outflows in the Complex Star-forming Environment of V1647 Ori and McNeil's Nebula

David A. Principe,[1,2 3★] Lucas Cieza, [2 3] Antonio Hales, [4 5] Alice Zurlo, [2 3] ...

M O V I N G   S N O W   L I N E S ?

Cieza et al. (2016)

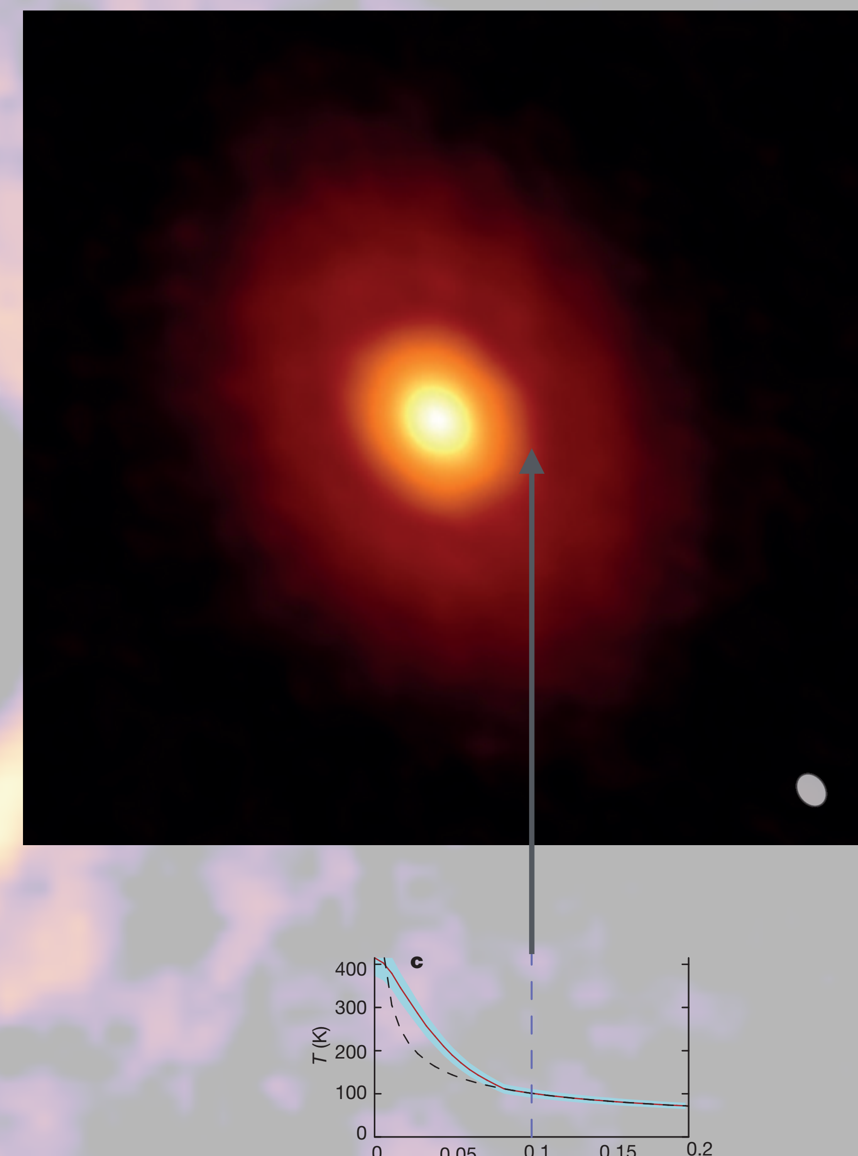

LETTER

doi:10.1038/nature18612

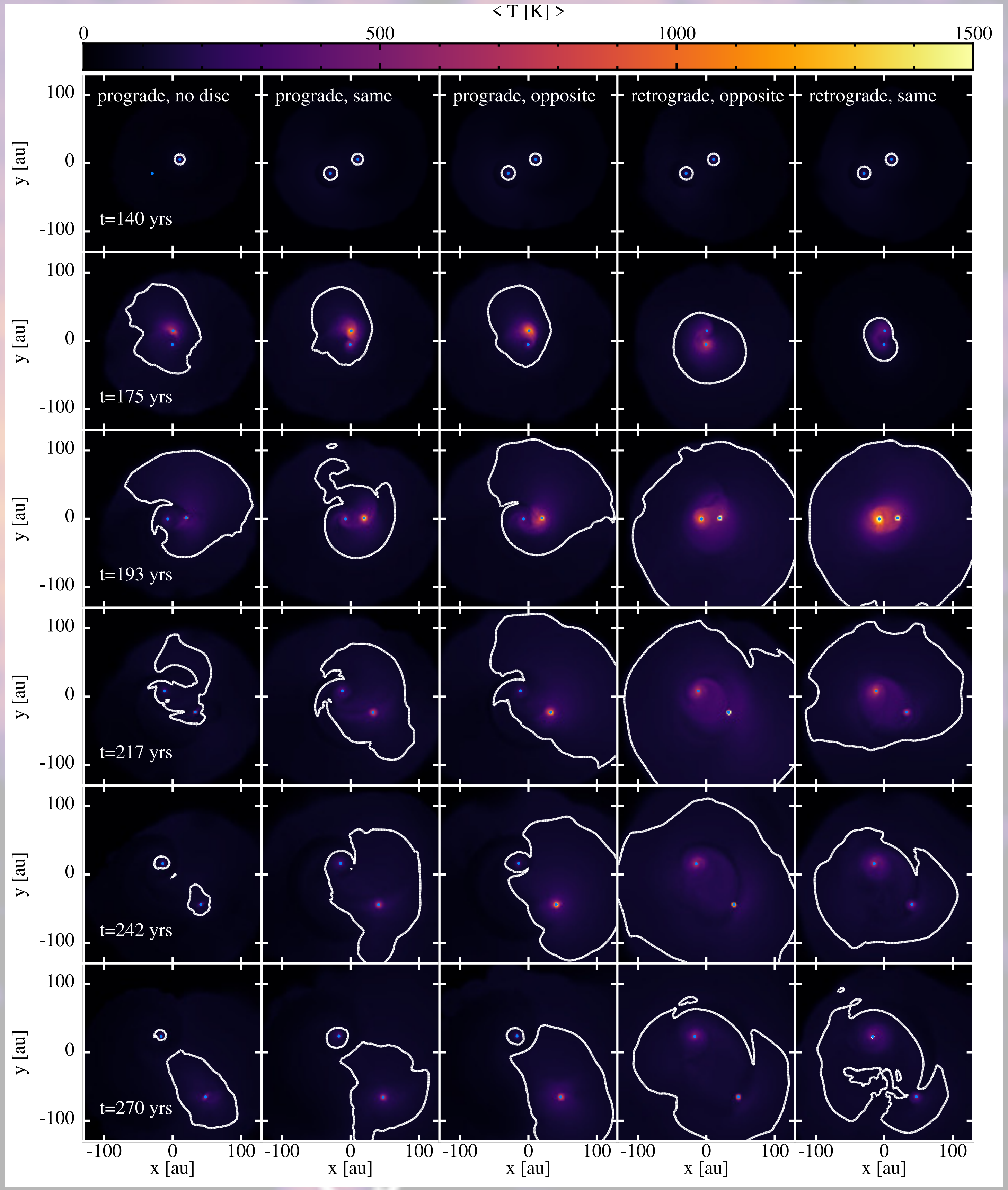
Imaging the water snow-line during a protostellar outburst

Lucas A. Cieza[1,2], Simon Casassus[2,3], John Tobin[4], Steven P. Bos[4], Jonathan P. Williams[5], Sebastian Perez[2,3], Zhaohuan Zhu[6], Claudio Caceres[2,7], Hector Canovas[2,7], Michael M. Dunham[8], Antonio Hales[9], Jose L. Prieto[1,10], David A. Principe[1,2], Matthias R. Schreiber[2,7], Dary Ruiz-Rodriguez[11] & Alice Zurlo[1,2,3]

- Water snow line moves to ~40 au during the outburst

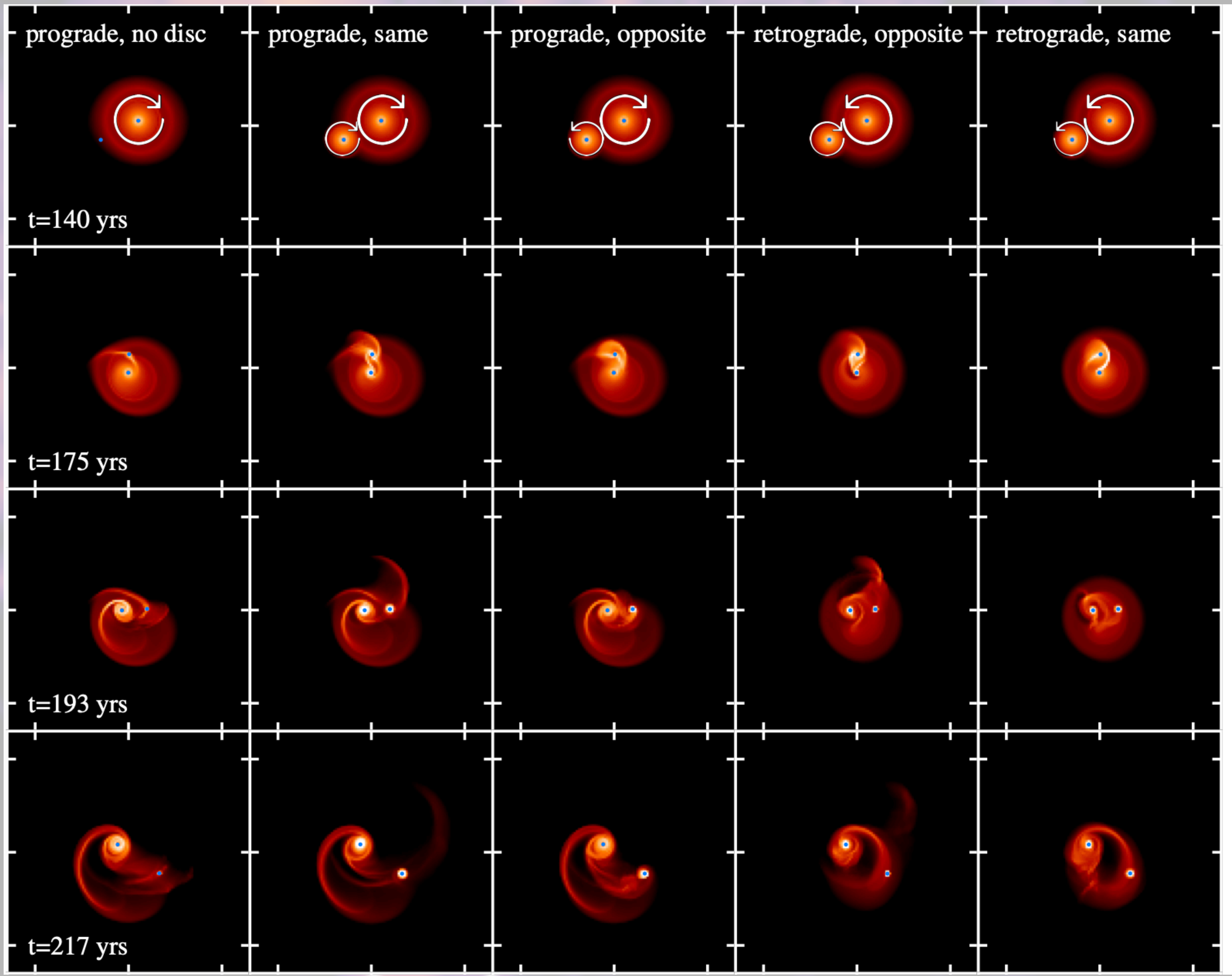


MOVING SNOW LINES?



Borchert et al. (2022, submitted)

WHAT IF THERE WERE DISCS AROUND BOTH STARS?



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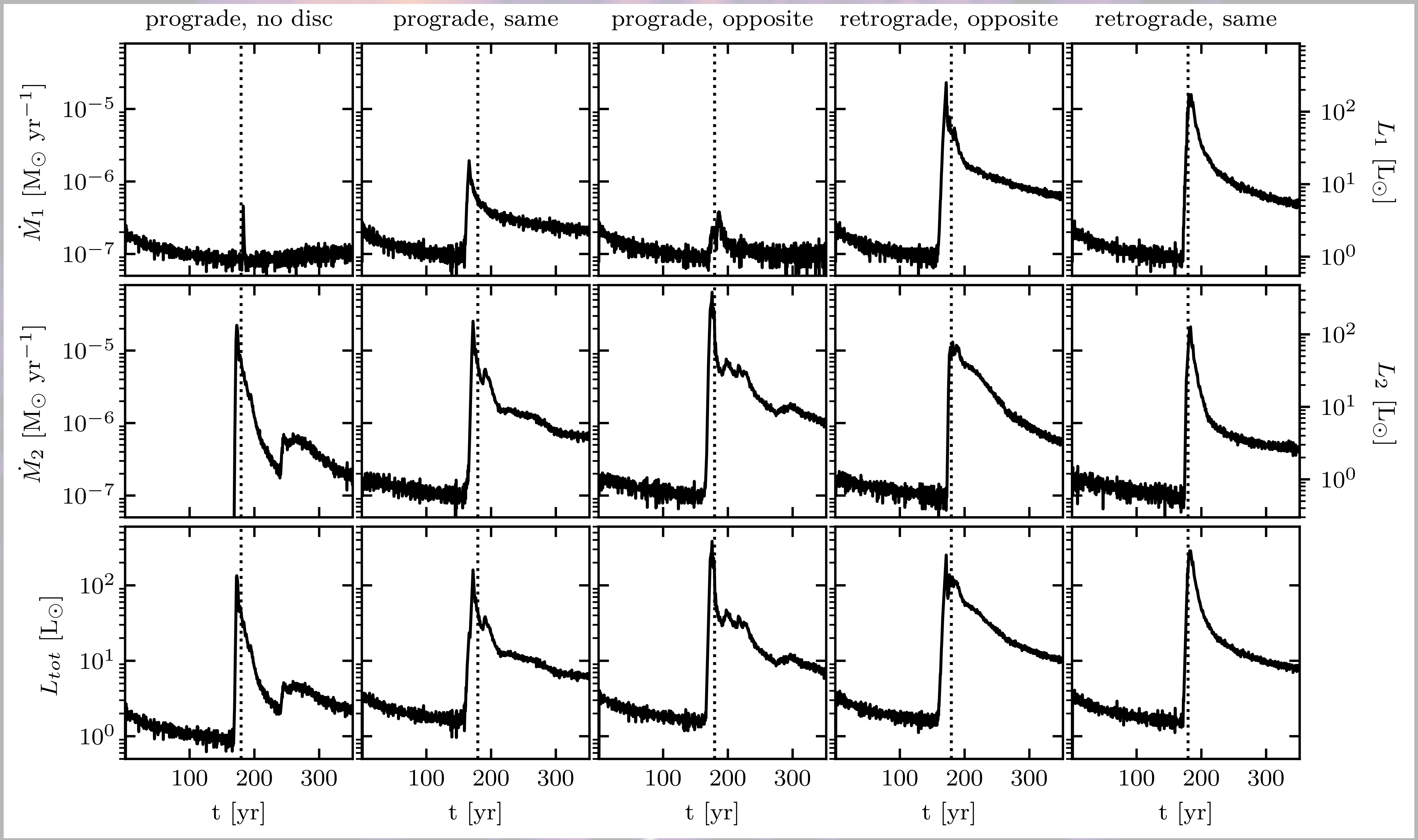


Sustained outbursts around ONLY low mass star or BOTH, but not primary alone

Borchert et al. (2022, submitted)

DID THE SOLAR SYSTEM HAVE A FLYBY?

Pfalzner et al. (2018)

The Astrophysical Journal, 863:45 (12pp), 2018 August 10
https://doi.org/10.3847/1538-4357/aad23c

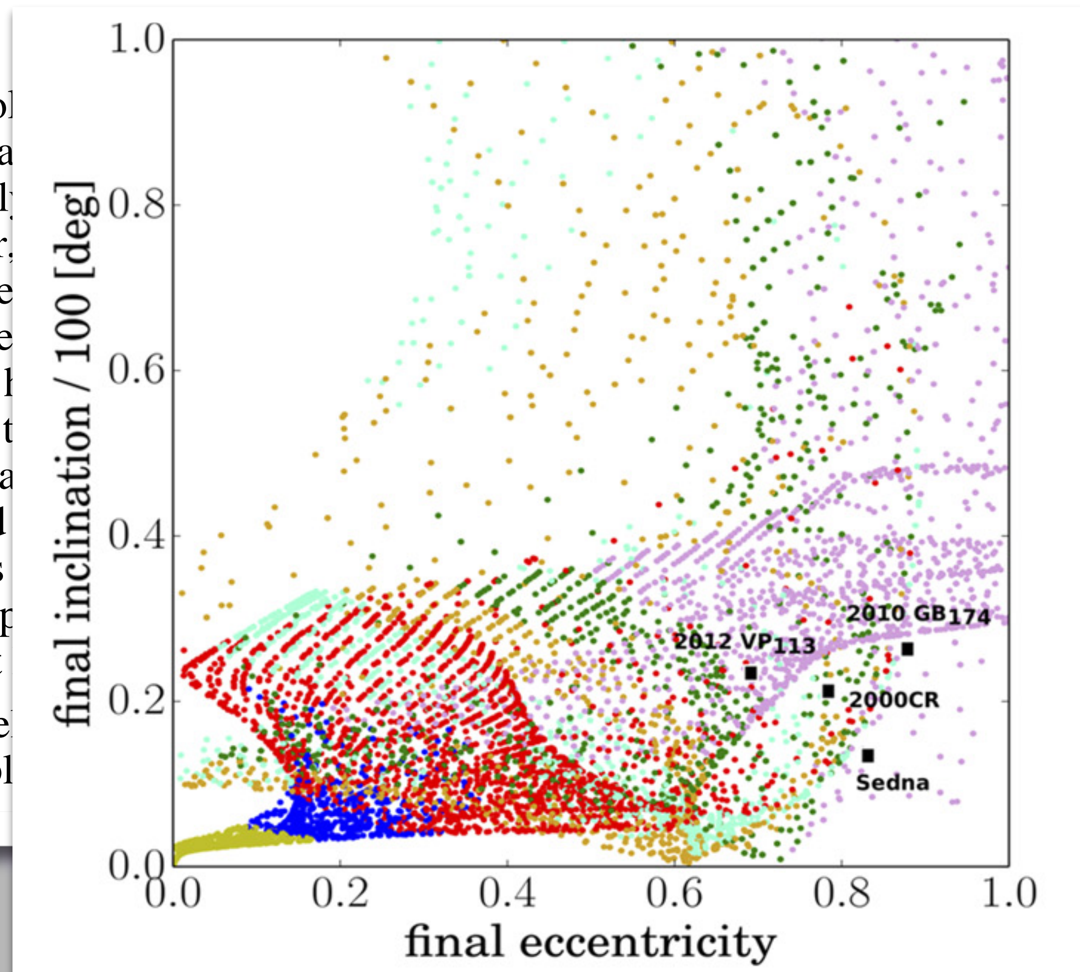
CrossMark

Outer Solar System Possibly Shaped by a Stellar Fly-by

Susanne Pfalzner[1], Asmita Bhandare[1,2], Kirsten Vincke[1], and Pedro Lacerda[3]
[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany; spfalzner@mpifr.de
[2] Max-Planck-Institut für Astronomy, Königstuhl 17 D-69117, Heidelberg, Germany
[3] Astrophysics Research Centre, Queen's University, Belfast, UK
Received 2018 May 10; revised 2018 July 1; accepted 2018 July 7; published 2018 August 9

The planets of our sol … me properties of the solar system that are peculia … l Neptune (trans-Neptunian objects [TNOs]) is only … s themselves, the TNOs do not orbit on coplanar, … l, eccentric orbits and are distributed in a comple … r system after its formation. However, some of the … uence of the planets. Thus, external forces must h … r solar system. The study presented here shows t … o the observed lower mass density outside 30 au a … family of Sednoids. In the past it was estimated … ment stage. However, our numerical simulations … anticipated. A fly-by also naturally explains the p … ulations suggest that many additional Sednoids at … ike the postulated planet X.

Key words: Kuiper be … d associations: general – planetary systems – pl …



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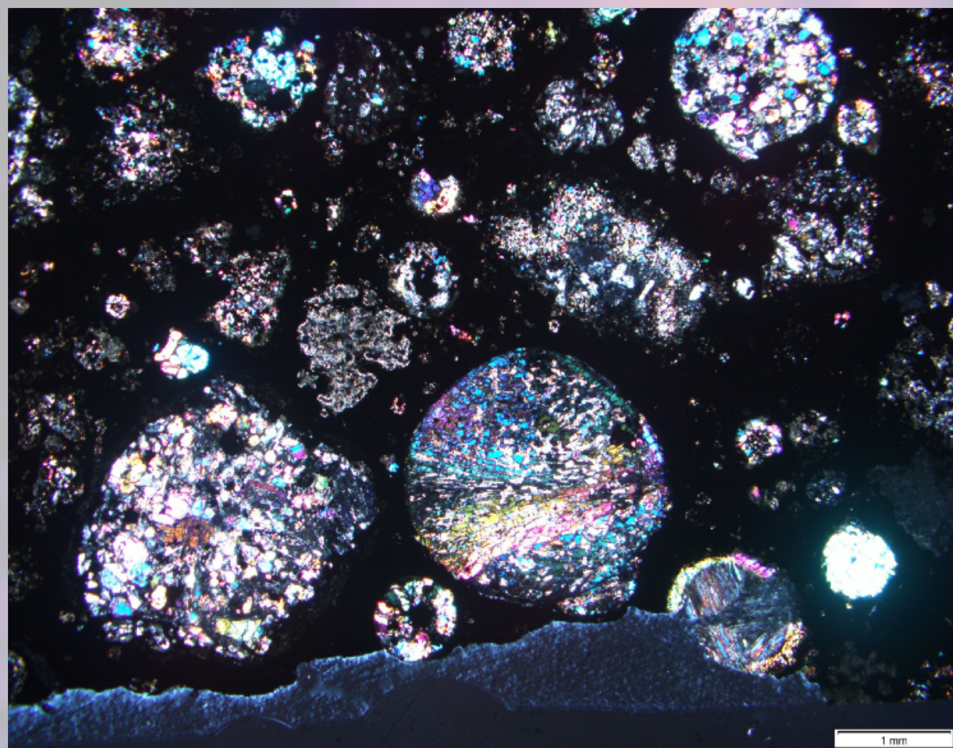
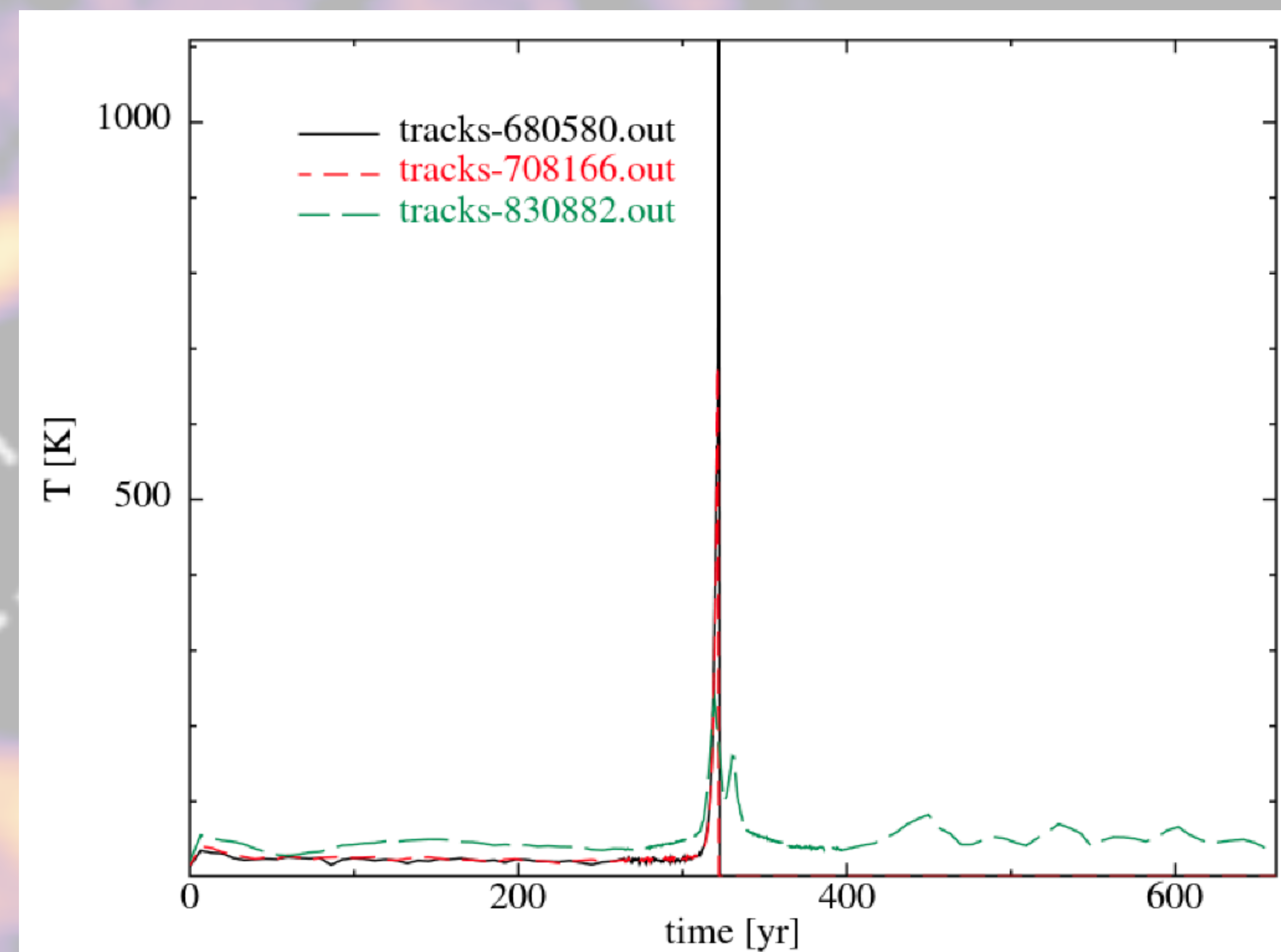
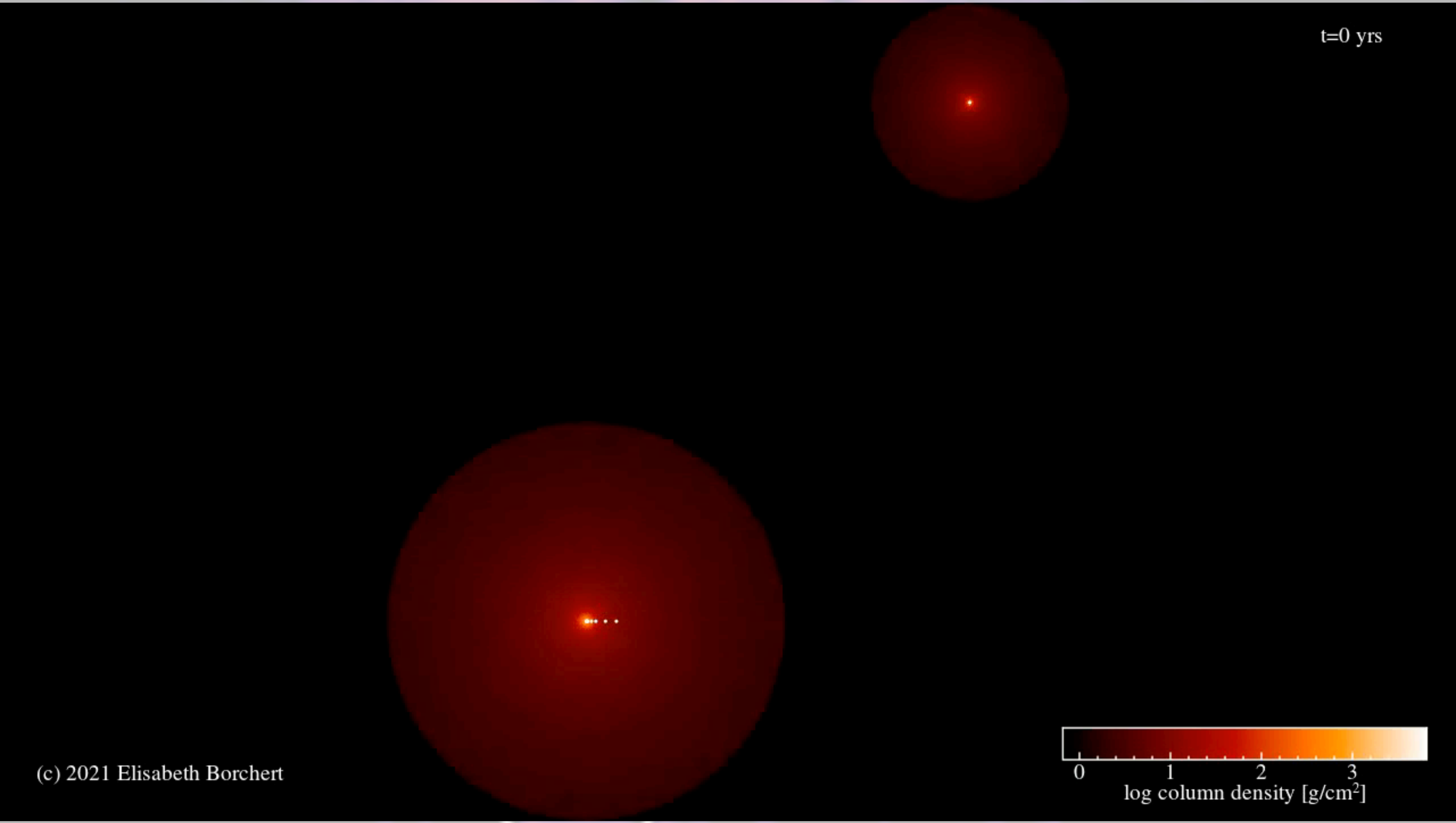


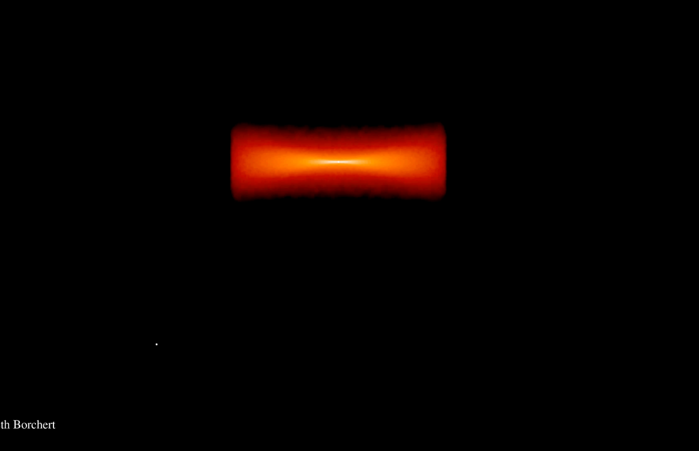
Chondrules in meteorites
Image credit: Elli Borchert
Meteorite credit: Andy Tomkins



Borchert, DP+ in prep

STEALING PLANETS?





SUMMARY

- FU Orionis shows strong observational evidence of being an interacting binary
- Can explain fast rise in $\dot{M}$ with disc-penetrating stellar flyby with periastron separation of ~10-20 au, consistent with current separation and differential motion
- ***Low mass star goes into sustained outburst, as observed***
- No requirement for thermal or other disc instabilities
- Can explain spectral weirdness, it's a low mass star with very high surface temperature (> 5000 K)
- Other phenomenology of outbursting young stars looks promising
- Possible implications for solar system, lots of other things to try!